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The Space Club

The Government has not yet crossed the Rubicon but it is busy paddling in the stream and gradually feeling its way into deeper water. Although the go-ahead signal has not yet been given to the conversion of Blue Streak into a satellite launcher, scarcely a week passes without a Minister making some reference to this possibility.

It has now been announced officially that Britain has proposed the formation of an organization, open to European and Commonwealth countries, for developing and producing rockets capable of putting heavy satellites into orbit—the so-called 'Satellite (or Space) Club.' This proposal will not be new to our members, for it is one that was first advanced by the Society and one which we have advocated for many months. Naturally, we heartily welcome the announcement—our only regret is that it was not made long before.

We hope that the proposal will also be welcomed by the countries to which it has been made. There can be no doubt about the participation of some Common wealth countries: to name only two, Australia is already closely associated with the United Kingdom in rocket development and the Woomera facilities would provide a useful 'Clubhouse'; Canada is engaged on an independent space research programme using United States vehicles but would obviously be interested in joining in the work of this new group. Even those countries which are quite small, or which have only recently achieved independence and are therefore not able to expend large sums for this purpose—even these would be able to offer facilities for a tracking station.

It is too early yet for European countries to have committed themselves concerning the proposal, although French and German immediate reactions were favourable. In reaching a decision whether to participate in the 'Club,' these countries will have to take account of the expenditure (both in money and manpower) involved—it is idle for us to pretend that it will be possible to run the club without membership subscriptions. However, there will be the benefits of membership to set on the credit side. We do not presume to suggest to the future Club Committee exactly what privileges an individual member should receive—that is obviously a matter for international negotiation and agreement—but it is likely that the benefits would

include the right to contribute instrumentation to the satellite payloads, access to the scientific information gained in space research, participation in any commercial projects (such as communication, navigation or weather satellites), and the possibility of taking part in the design and development of future space vehicles.

There is also the intangible benefit of the prestige associated with participation in space technology, although many will feel that the prestige conferred by membership of the Satellite Club can hardly be comparable with that which the U.S.A. and U.S.S.R. possess as a result of their do-it-yourself space activities. We cannot agree wholly with that reservation, for we feel that a project undertaken internationally must possess some special merit. Although competition between America and Russia has undoubtedly acted as a spur and accelerated progress in astronautics, how much better it would be if the first astronauts were primarily thought of as Terrans and only secondarily as Russians or Americans—if their nationality counted for as little as their home town or their county, state or republic.

Any Satellite Club that is established will have an excellent opportunity for showing that men of various nations can work together for the common good without following the example of Babel. There are, of course, a number of other projects where this type of cooperation is already proving fruitful—we need only mention OEEC, the Common Market and the Free Trade Area.

Just because of the international nature of the proposed Space Club, we consider it important that its *ultimate* objectives should include manned spaceflight. Emphasis is placed on this being an ultimate, rather than immediate, objective, for even were the money available to finance the development of a manned spacecraft, it is obviously desirable to begin by developing simpler vehicles. However, it should be frankly recognized from the start that although the Club's initial purpose would be to launch satellites, its range of activities would undoubtedly increase with the passing years. It would not be a very expensive matter to have a small team working from the very beginning on a preliminary design study for a manned vehicle—not necessarily an advanced spaceship: an antipodal rocket transport, perhaps.

These questions and others of equal importance will be considered much more fully both at government level and publicly in the discussions at the European Symposium on Space Technology which this Society is organizing in June. We trust that by the time the Symposium is held the Space Club will be in existence, and we hope that the Government will show a greater sense of urgency in this matter. There is no reason for them to think that a decision to undertake satellite research would be highly unpopular—if anything the electorate is more favourable to the idea than is the government. The resolution passed at the recent Conservative Party Conference provides some evidence of this. The Labour Party is unlikely to take a markedly different view. After all, turning Blue Streaks into satellite launchers can be considered the modern equivalent of turning swords into ploughshares.

G. V. E. THOMPSON.

THE CHEMISTRY OF MARS. I. THE ATMOSPHERE*

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ABSTRACT

Probable composition and properties of the Martian atmosphere are reviewed.

I. INTRODUCTION

THAT Mars possesses an atmosphere has been known for many years, for all observers of the planet have reported the haziness and obscurity of surface features typical of atmospheric phenomena. However the extent and composition of the Martian atmosphere has long remained a mystery and even to the present day it is difficult to find satisfactory answers to most of the problems and certainly no final conclusions can be drawn.

II. EXTENT OF THE ATMOSPHERE

Early investigations[1] of Mars, using photographic techniques with plates sensitive to various regions of the spectrum, clearly established the presence of a dense atmosphere, for ultra-violet photographs showed no surface details. However, it was impossible to arrive at accurate estimates of the height of the atmosphere from the photographs, owing to the poor resolution.

Modern work has used a variety of methods to determine the height and density of the planet's atmosphere. Hess[2], for example, has studied the tenuous white clouds which occasionally form. He has shown that, assuming them to be composed of water in some physical state, their presence can be accounted for if about 0·5 mm. pressure of water vapour exists at the surface. From his studies he concludes that the total mass of the atmosphere must be about one fifth that of Earth's. The height of a hypothetical ionosphere in such an atmosphere must be about 70 km. from the surface of Mars.

In other studies, Dollfus[3] has attempted to estimate the total molecular content by careful determinations of the scattering power of the Martian atmosphere under conditions of minimum haze. His best values show that taking the Earth's atmosphere as unity, the scattering power of the atmosphere of Mars is 0·22. Assuming the composition to be without appreciable effect on the scattering power (see below), this value is in close agreement with the previous estimate.

An attempted revision of Dollfus' value has been undertaken[4] in the hope of allowing for the effects of scattering by small particles, as distinct from the assumed molecular scattering. The revised value of 0·20, however, is of little significance to the present discussion.

III. COMPOSITION OF THE ATMOSPHERE

For convenience the atmosphere of a planet can be considered in two parts—gas and clouds—though this distinction is not to be taken as a physical one for all possible intermediates may exist.

Spectroscopic studies of Mars have produced mainly negative results. The only definite conclusion is the presence of small amounts of carbon dioxide.[5] Estimates of the total amount of this gas present on Mars have been made from the observations.[6] Assuming that the atmospheric pressure at the Martian surface is about 100 millibars it would seem that the fraction of carbon dioxide by volume is fifty times greater, and the total amount of the gas is about ten times greater than the Earth's.

Spectroscopic evidence of the presence of other gases is questionable. Early workers[7] compared the integrated intensity of a molecular band of the spectrum of Mars with a similar band of the spectrum of the Moon at the same altitude. Claims to have detected slight displacements due to water vapour and oxygen were made and later results[8,9] also indicated the presence of oxygen in the Martian atmosphere, but other workers were unable to repeat the experiments.[10]

More recent investigations[11] have concluded that the amount of oxygen can be no more than 0·003 times that of the Earth.

That water vapour must be present in the atmosphere even if in only very small quantities, is a conclusion to be drawn from the nature of the polar caps of Mars. Studies of the properties of the caps have been made[12] and it is reasonably certain that they are composed of water, in the form of frost at low temperatures. The seasonal melting of this water must produce a slight increase in the water vapour content of the atmosphere as a whole.

The presence of other bodies of water, or frost, elsewhere on Mars is doubted, though reports of strange flashes from the surface have been made from time to time[13]. It is possible that these may be reflections from isolated ice-beds, perhaps on high points, which may also contribute to a very small extent to the total atmospheric water vapour.

Of the other gases which might be predicted to be present, nitrogen and argon are the two most likely, but

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neither can be detected spectroscopically, owing to the inaccessibility of their lines. Nevertheless there are reasons to suppose that they may occur on Mars.

Argon forms about 0·9% of the Earth's atmosphere (by volume). Examination of the gas has shown that it occurs in three isotopic forms, but 99·633% is ^{40}A, possibly derived from ^{40}K by radioactive decay[14]. Almost all the argon in the Earth's atmosphere may have been produced from potassium atoms in the solid crust. Assuming that argon can be retained within the gravitational field of a planet, which is the case for both Earth and Mars, the concentration of the gas in a planet's atmosphere will be roughly proportional to the amount of potassium present. Approximately 2·59% of the Earth's crust is potassium and it is probable that the amount on Mars will be no less. In fact, considering the low overall density of the planet, it is possible that relatively light elements, such as potassium, may be present in far larger amounts than on Earth. It is therefore reasonable to assume that the amount of argon on Mars will be similar or greater than the amount on Earth.

But carbon dioxide, water vapour, oxygen and argon can be only minor constituents of the atmosphere of Mars. Of the major constituent(s) there is no information, other than the negative evidence that it is not ammonia, methane, or any other gas with well-defined absorptions in the available spectrum. The usual assumption about the remainder is that it is nitrogen. Some evidence for this assumption comes from the previously discussed scattering power. Considerations[15] of the known scattering power of gases have shown that the assumption that the Martian atmosphere has the composition 95–96% nitrogen, 4–5% argon, 0·03% carbon dioxide, with traces of other gases, provides close agreement with observation.*

IV. CLOUD FORMATIONS

A number of quite different types of atmospheric phenomena has been reported to obscure the surface features of Mars. Of these, the most common is unquestionably a general haziness which is almost universally present; so much so that it was once considered to be due to some property of the gases of the atmosphere rather than to a form of cloud. This view is untenable, however, for several observers[16] have reported occasional clearings during which the surface details show through very clearly.

The haziness is probably associated with the so-called "blue haze" or "violet layer" of the atmosphere. Photographs of Mars with suitably sensitive plates have revealed the existence of atmospheric matter reflecting the blue and violet wavelengths, but transparent to most others. Studies of the blue haze[17] have shown that it may be explained in terms of a layer, several kilometres thick, of ice crystals about half a micron in diameter, situated about 30 or 35 kilometres above the surface. However, the haze particles absorb in the blue and near-ultra-violet while ice (and solid carbon dioxide) does not.

Other explanations of the blue haze have been offered however; a now discarded hypothesis regarded it as layers of particles of solid carbon dioxide. A more recent suggestion[18] that will bear more detailed investigation considers the haze to be caused by a layer of particles of lampblack (C_n molecules).†

At least two other types of cloud occur in the Martian atmosphere.[19] One of these is white; the other yellow in general appearance in the telescope.

Polarization studies of the former[20] have suggested that they too are composed of ice crystals, though it is possible that the ice may be in equilibrium with water in the liquid phase. These clouds may fall as snow to form the polar caps, but a rainfall is unlikely as ice under these conditions would evaporate before melting. Estimates of the height of the white clouds have been made[21] and it seems that they are considerably nearer to the surface than the blue haze; perhaps about 20 km. high.

An interesting feature of these clouds is their apparent tendency to form or accumulate over particular surface areas.[22] The reason for this phenomenon is obscure, as the Martian surface has no large prominences such as mountains—over which terrestial clouds tend to form owing to the favourable meteorological conditions. It would seem that the areas over which the clouds form may be associated with the release of relatively large amounts of water vapour, though the problem is open to many interpretations.

The final Martian cloud type is yellow in colour and probably close to the surface. That they are due to dust storms of some sort is likely, but the wind speeds on Mars are low and dust may be raised by local turbulence rather than widespread winds.

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* *Note added in proof.* Hence the recent report[26] that examinations of the reflection spectrum of Mars shows details characteristic of nitrogen tetroxide must be viewed with some scepticism. It appears most unlikely that a compound as reactive as nitrogen tetroxide could be a survivor of the primitive Martian atmosphere. If present it is most likely that it is continually generated from its constituent elements.

A possible site for this reaction is the upper atmosphere, where the reactions:

(i) $N_2 + h\nu \rightleftharpoons 2N$

(ii) $H_2O + h\nu \rightleftharpoons 2H + O$

(iii) $N + O \rightleftharpoons NO + h\nu$

(iv) $NO + O \rightleftharpoons NO_2$

may occur. If this is the case, nitrogen tetroxide may be only a minor constituent of the Martian atmosphere, occurring mainly in the higher levels. In fact, the above reactions probably occur more readily in the terrestrial atmosphere and the concentration of nitrogen tetroxide on Earth is probably greater than that on Mars. A further oxide of nitrogen, nitrous oxide, is a well-known[27,28] minor component of the Earth's atmosphere: occurring in concentrations about equal to atmospheric ozone.

† *Note added in proof.* However, if vegetation analogous to terrestrial plants does occur on the surface of Mars, the haze may be a product of the Martian vegetation. It is thought, for example, that the Earth's atmosphere contains large amounts of terpene-like hydrocarbons in the form of particles $<0{\cdot}1\ \mu$.[29] The blue haze of Mars may be due to a similar phenomenon.

V. CONCLUSIONS

The information presented above indicates the lack of detail in the modern picture of the atmosphere of Mars.[23,24] Nevertheless a number of important conclusions can be deduced from the presumed nitrogen, argon, and carbon dioxide atmosphere containing clouds of water, ice and dust.

Of particular interest is the almost complete absence of free oxygen and water. It remains for the proponents of the vegetation-hypothesis of the Martian surface markings to explain these absences; particularly of oxygen. The oxygen lack will also render the formation of an ozone layer similar to that of the Earth impossible. The resulting higher intensity of ultraviolet radiation that will reach the surface is a second factor that is of importance to any supposed vegetation.

The presence of carbon dioxide raises interesting questions that cannot be answered. Urey[25] has maintained that the concentration of this gas in the terrestial atmosphere is a function of the equilibrium of the reversible reaction of silicon dioxide with magnesium carbonate. A similar situation will presumably apply to Mars. In the absence of a process such as photosynthesis to constantly reduce the amount of carbon dioxide in the atmosphere it follows from Urey's treatment of the problem that increased weathering of rocks will occur to restore the equilibrium. In view of the present state of the Martian surface, which is probably greatly weathered, it is possible that Mars offers a test of a general hypothesis of silicate planetary surfaces.

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ON THE MOTION OF A PARTICLE ABOUT AN OBLATE SPHEROID
II. CALCULATION OF THE TIME OF FLIGHT*

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(Communication from de Havilland Propellers Ltd.)

ABSTRACT

In a previous paper[1] the results of a solution of the equations of motion of a particle about an oblate spheroid to the first order of perturbations, using the method of Variation of Elements, were presented.

Numerical applications of the theory indicated the presence of an error in the time of flight equation. Three possible sources of the error in the theory are considered. The error is found to arise from the omission of a term in the equation for the rate of change of the mean longitude of the epoch. A theoretical expression for the correction required by the time of flight is derived.

I. INTRODUCTION

THE previous part[1] gave the results of a theoretical investigation into the motion of a particle about an oblate spheroid—*e.g.*, the Earth—under the influence of gravitational forces alone. The method employed was that of "Variation of Elements" and simple solutions

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were obtained for the variations, accurate to the first order in J—the coefficient of the principal perturbation due to the oblateness of the spheroid.

To check the accuracy of the solution—which was programmed for a Pegasus computer—a number of test cases were considered. In each case a set of initial conditions was adopted and the position, velocity and time at a given geocentric distance were predicted. The predictions thus obtained were checked against those derived by direct numerical integration of the basic equations of motion, the latter taking full account of the J terms.

It was found that the predicted positions and velocities, in inertial space, agreed completely but that there was a small difference in the time of flight. This error was definitely established as a real error and not an error in numerical work.

The error in the time of flight is directly an error in the value of the element σ at the predicted point. This element is the mean longitude of the epoch in the osculating ellipse. As the numerical investigation was conducted in terms of time as independent variable the error was necessarily ascribed to the variational solution.

II. SOURCE OF THE ERROR

The error in the analytical calculation of σ could arise from any one of three sources:

(*i*) the neglect of second and higher order terms in J in the analytic solution;

(*ii*) an error in transforming the basic variational equations to render them suitable for analytic integration;

(*iii*) an error in the basic equation used for $\dot{\sigma}$.

The first possible error source can be excluded on two grounds. The numerical integration is accurate to all orders of J and shows that for the other elements the contributions of the second order terms, in the cases considered, were entirely negligible. As further confirmation, although the time of flight errors were small, the proportional errors in the calculated variation $\Delta\sigma$ in σ were of the order of 25%—an amount that can hardly be called second order.

The second possible source was next examined. The basic equations to be solved were of the form:

$$\dot{\alpha}_i = J \times F(\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6; r, f) \quad .. \quad (67)$$

where α_i denotes any one of the six elements, r the geocentric distance and f the true anomaly. As Equation (67) shows that $\Delta\alpha_i (= \int \dot{\alpha}_i dt)$ is of the order of J, the normal method of substituting initial values of α_1 to α_6 for their current values, on the right hand side, was adopted. The terms thus neglected were of the second order in J. For r the substitution:

$$r = \frac{a(1-e^2)}{1 - e\cos f} \quad .. \quad .. \quad (68)$$

was made, this following from the definition of the osculating ellipse. Thus Equation (67) became:

$$\dot{\alpha}_i = J \times F'(f) \quad .. \quad .. \quad (69)$$

Provided that the eccentricity of the osculating ellipse is small, one may derive a series expansion for f in terms of t. For the general case this approach is unsuitable. To obtain Equation (69) in an integrable form the independent variable was therefore transformed from time, t, to true anomaly, f.

In the osculating ellipse at any time, we have, by definition:

$$r^2\dot{f} = h = \sqrt{\mu a(1-e^2)} \quad .. \quad (70)$$

Then $\frac{d}{df} = \frac{dt}{df}\cdot\frac{d}{dt}$, whence,

$$\frac{d\alpha_i}{df} = \frac{r^2}{h} \times J \times F'(f) \quad .. \quad .. \quad (71)$$

Substituting for r from Equation (68) and writing h_0, the initial value, for h, the six equations (71) where then integrable.

The validity of this step is confirmed by two arguments. The results for five of the six variations were correct and further, although h varies with time as a and e vary, the variation in h is of order J and allowing for this would only introduce second order terms.

This can be confirmed theoretically. Physically one would expect Equation (70), for the perturbed motion, to be of the form:

$$r^2\{\dot{f} + \dot{\omega} + \dot{\Omega}\cos\theta_m\} = h \quad .. \quad (72)$$

Following Egorov[2], we write the equation of the ellipse in the form:

$$r[1 + e\cos f] = a(1-e^2) = p$$

Differentiating totally,

$$\dot{r}[1 + e\cos f] + r\cos f.\dot{e} - re\sin f.\dot{f} = \dot{p} \quad .. \quad (73)$$

By the definition of the osculating ellipse,

$$\dot{r} = e\sin f.\sqrt{\frac{\mu}{p}} \quad .. \quad .. \quad (74)$$

Then from Equations (73) and (74):

$$r^2\left\{f - \frac{\cos f}{e\sin f}\dot{e} + \frac{p}{re\sin f}\right\} = h \quad .. \quad (75)$$

From the variational equations in the previous paper[1] we have:

$$\left.\begin{aligned} \dot{p} &= \frac{2\sqrt{1-e^2}}{na}\, r.T \\ e &= \frac{\sqrt{1-e^2}}{na}\, S\sin f + \frac{\sqrt{1-e^2}}{na^2e}\left\{\frac{ap}{r} - r\right\}T \end{aligned}\right\} \quad (76)$$

Then Equation (75) becomes:

$$r^2\left[\dot{f}-\frac{\sqrt{1-e^2}}{nae}S\cos f+\right.$$
$$\left.+\frac{\sqrt{1-e^2}}{nae}\left(1+\frac{r}{p}\right)T\sin f\right]=h \quad .. \qquad (77)$$

But, from the previous paper, we have:

$$\dot{\omega}+\dot{\Omega}\cos\theta_m$$
$$=-\frac{\sqrt{1-e^2}}{nae}S\cos f+\frac{\sqrt{1-e^2}}{nae}\left(1+\frac{r}{p}\right)T\sin f$$
$$.. \qquad (78)$$

and thus Equation (72) is proved. It follows that:

$$r^2\dot{f}=h-r^2[\dot{\omega}+\dot{\Omega}\cos\theta_m]=h_0-J\times G(f) \quad .. \quad (79)$$

where $G(f)$ is a function of f and the elements as given by Equation (78). Use of Equation (72) in the transformation to f as independent variable would thus only add second order terms.

It was therefore concluded that the error could only lie in the equation for σ. This was:

$$\dot{\sigma}=-\sqrt{1-e^2}[\dot{\omega}+\dot{\Omega}\cos\theta_m]-\frac{2rS}{na^2} \quad .. \quad (80)$$

and was derived from the Lagrangian equation:

$$-\tfrac{1}{2}na\dot{\sigma}-\tfrac{1}{2}na\sqrt{1-e^2}\,[\dot{\omega}+\dot{\Omega}\cos\theta_m]=\frac{\partial V}{\partial a} \qquad (81)$$

where $V=(\mu J\delta^2/r^3)(3\sin^2\theta-1)$, the perturbing potential. In the full Lagrangian form Equation (81) is:

$$[a,a]\dot{a}+[a,e]\dot{e}+[a,\sigma]\dot{\sigma}+[a,\omega]\dot{\omega}+[a,\Omega]\dot{\Omega}+$$
$$+[a,\theta_m]\dot{\theta}_m=\frac{\partial V}{\partial a}$$

where $[\alpha_i,\alpha_j]$ is a Lagrangian Bracket (see Smart[3]). This equation was now examined in detail.

The first investigation was to check the expressions for the Lagrangian brackets $[a,\alpha_i]$. The standard methods of the textbooks were disregarded and an independent check conducted. The textbook results were confirmed.

Considering next the right-hand side, $\partial V/\partial a$, it is an elementary step to show that, in terms of the orthogonal force components S, T and W, of the previous paper,[1]

$$\frac{\partial V}{\partial a}=S\frac{\partial r}{\partial a}+rT.\frac{\partial f}{\partial a} \quad .. \quad .. \qquad (82)$$

Now we have the following standard relations:

$$\left.\begin{aligned} r&=a[1+e\cos E]\\ \tan(E/2)&=\left\{\frac{1+e}{1-e}\right\}^{\frac{1}{2}}\tan(f/2)\\ a\sqrt{1-e^2}\sin E&=r\sin f\\ E+e\sin E&=nt+\sigma \end{aligned}\right\} .. \qquad (83)$$

whence:

$$\frac{dr}{da}=\frac{r}{a}-ae\sin E.\frac{\partial E}{\partial a}$$
$$\frac{\partial f}{\partial a}=\frac{a\sqrt{1-e^2}}{r}\frac{\partial E}{\partial a}$$
$$\frac{\partial E}{\partial a}=-\frac{3nt}{2r}$$

Then, $\dfrac{\partial V}{\partial a}=S\dfrac{r}{a}+[S\,ae\sin E-T.a\sqrt{1-e^2}]\dfrac{3nt}{2r}$ (84)

Now from the previous paper:

$$\frac{rn}{2}.\dot{a}=-\frac{e}{\sqrt{1-e^2}}r\sin f.S+a\sqrt{1-e^2}.T$$
$$\dot{a}=-\frac{2a}{3n}\dot{n} \quad .. \quad .. \quad .. \qquad (85)$$

Whence:

$$\frac{\partial V}{\partial a}=S\frac{r}{a}+\frac{na}{2}.t\dot{n}$$

The result quoted in the textbooks is $\partial V/\partial a=Sr/a$ derived by writing nt as $\int ndt$, where n is *not* to be regarded as a function of a (see Smart[3], p. 220).

Hence the equation for $\dot{\sigma}$ becomes:

$$\dot{\sigma}=-\sqrt{1-e^2}[\dot{\omega}+\dot{\Omega}\cos\theta_m]-\frac{2rS}{na^2}-t\frac{dn}{dt} \qquad (86)$$

If we write σ' for the value of σ found in the previous paper[1], then:

$$\sigma=\sigma'-\int t\frac{dn}{dt}\,dt \quad .. \quad .. \qquad (87)$$

This is equivalent to stating that the previous result was derived from the equation for $\dfrac{d}{dt}(nt+\sigma)$, the differentiation being performed only so far as t appears *implicitly*.

III. CORRECTION TO THE TIME OF FLIGHT

The time of flight is derived from

$$t_F=\frac{1}{n}[E+e\sin E]-\frac{\sigma'}{n} \quad .. \qquad (88)$$

in the Pegasus programme, with n, e, E, σ' being the perturbed osculating elements. From Equation (87) it follows that the correction is

$$\Delta t_F=\frac{1}{n}\int_0^{t_F}t\frac{dn}{dt}\,dt \quad .. \quad .. \qquad (89)$$

Integrating by parts:

$$\Delta t_F=\frac{1}{n}[t_F\Delta n]-\frac{1}{n}\int_0^{t_F}\Delta n.dt \quad .. \qquad (90)$$

Transforming by Equation (70),

$$\frac{1}{n}\int \Delta n.dt = \frac{1}{nh_0}\int_{f_0}^{f} r^2\Delta n df = \frac{-3}{2a_0h_0}\int_{f_0}^{f} r^2\Delta a df$$

$$= \frac{-3p_0^2}{2a_0h_0}\int_{f_0}^{f}\frac{\Delta a}{(1-e_0\cos f)^2}df \quad .. \quad (91)$$

Now from the previous paper we have symbolically

$$\Delta a = C\left\{\sum_{j=0}^{5}[A_j\cos jf + B_j\sin jf] - \right.$$

$$\left. - \sum_{j=0}^{5}[A_j\cos jf_0 + B_j\sin jf_0]\right\} \quad .. \quad (92)$$

where C, A_0 to A_5, B_0 to B_5 are constants independent of f. Then writing:

$$D_0 = \sum_{j=0}^{5}\{A_j\cos jf_0 + B_j\sin jf_0\} \quad .. \quad (93)$$

$$I(j,m) = \int_{f_0}^{f}\frac{\sin jf}{(1-e_0\cos f)^m}df \quad .. \quad (94)$$

$$K(j,m) = \int_{f_0}^{f}\frac{\cos jf}{(1-e_0\cos f)^m}df \quad .. \quad (95)$$

Then

$$\frac{1}{n}\int_0^{t_F}\Delta n.dt$$

$$= \frac{-3p_0^2C}{2a_0h_0}\left[\sum_{j=0}^{5}\{A_jK(j,2) + B_jI(j,2)\} - D_0K(0,2)\right] \quad (96)$$

Now

$$I(j,1) = \int_{f_0}^{f}\frac{\sin jf}{1-e_0\cos f}df$$

$$= \left\{\frac{-\cos jf}{j(1-e_0\cos f)}\right\}_{f_0}^{f} - \frac{e_0}{j}\int_{f_0}^{f}\frac{\cos jf.\sin f}{(1-e_0\cos f)^2}df$$

Then using

$\cos jf.\sin f = \frac{1}{2}\{\sin(j+1)f - \sin(j-1)f\}$

and defining

$$I^*(j,m) = \left\{\frac{\cos jf}{(1-e\cos f)^m}\right\}_{f_0}^{f} \quad .. \quad (97)$$

We obtain

$$I(j,2) = I(j-2,2) - \frac{2}{e_0}(j-1)I(j-1,1) -$$

$$- \frac{2}{e_0}I^*(j-1,1) \quad .. \quad .. \quad (98)$$

Similarly, defining $K^*(j,m) = \left\{\frac{\sin jf}{(1-e\cos f)^m}\right\}_{f_0}^{f}$ (99)

$$K(j,2) = K(j-2,2) - \frac{2}{e_0}(j-1)K(j-1,1) +$$

$$+ \frac{2}{e_0}K^*(j-1,1) \quad .. \quad .. \quad (100)$$

The correction to the time of flight is then:

$$\Delta t_F = \frac{1}{n}t_F\Delta n +$$

$$+ \frac{3p_0^2C}{2a_0h_0}\left\{\sum_{j=0}^{5}[A_jK(j,2) + B_jI(j,2)] - D_0K(0,2)\right\}$$

.. (101)

Calculation of Equation (101) for a test case proved that the time of flight error was eliminated.

APPENDIX

Expressions and Formulae for Evaluating Δt_F

We have

$$\Delta t_F = \frac{1}{n}.t_F\Delta n + \frac{3p_0^2C}{2a_0h_0}\left\{\sum_{j=0}^{5}[A_jK(j,2) + B_jI(j,2)] - \right.$$

$$\left. - D_0K(0,2)\right\}$$

$$D_0 = \sum_{j=0}^{5}[A_j\cos jf_0 + B_j\sin jf_0]$$

$$I(5,2) = I(3,2) - \frac{8}{e_0}I(4,1) - \frac{2}{e_0}I^*(4,1)$$

$$I(4,2) = I(2,2) - \frac{6}{e_0}I(3,1) - \frac{2}{e_0}I^*(3,1)$$

$$I(3,2) = I(2,2) - \frac{4}{e_0}I(2,1) - \frac{2}{e_0}I^*(2,1)$$

$$I(2,2) = -\frac{2}{e_0^2}\left\{\log[1-e_0\cos f] + \frac{1}{1-e_0\cos f}\right\}_{f_0}^{f}$$

$$I(1,2) = -\frac{1}{e_0}\left\{\frac{1}{1-e_0\cos f}\right\}_{f_0}^{f}$$

$$I(0,2) = 0$$

$$I^*(j,1) = \left\{\frac{\cos jf}{1-e_0\cos f}\right\}_{f_0}^{f}$$

$$I(1,1) = \frac{1}{e_0}\left\{\log\,[1 - e_0\cos f]\right\}_{f_0}^{f}$$

$$I(2,1) = \frac{2}{e_0^2}\left\{\log\,[1 - e_0\cos f] - [1 - e_0\cos f]\right\}_{f_0}^{f}$$

$$I(3,1) = 3I(1,1) + \frac{16}{e_0}\left\{\frac{1}{2(1+x)^2} + \frac{1-e_0}{2e_0}\cdot\frac{1}{1+x} + \frac{1-e_0^2}{4e_0^2}\log\left(\frac{1+\gamma^2 x}{1+x}\right)\right\}_{f_0}^{f}$$

where $x = \tan^2(f/2), \gamma^2 = \dfrac{1+e_0}{1-e_0}$

$$I(4,1) = \frac{4}{e_0^4}\left\{(2-e_0^2)\log z - (6-e_0^2)z + 3z^2 - \frac{2}{3}z^3\right\}_{f_0}^{f}$$

where $z = 1 - e_0\cos f$

$$K(5,2) = K(3,2) - \frac{8}{e_0}K(4,1) + \frac{2}{e_0}K^*(4,1)$$

$$K(4,2) = K(2,2) - \frac{6}{e_0}K(3,1) + \frac{2}{e_0}K^*(3,1)$$

$$K(3,2) = K(1,2) - \frac{4}{e_0}K(2,1) + \frac{2}{e_0}K^*(2,1)$$

$$K(2,2) = K(0,2) - \frac{2}{e_0}K(1,1) + \frac{2}{e_0}K^*(1,1)$$

$$K(1,2) = \frac{1}{(1-e_0^2)^{3/2}}\left\{e_0 E + \sin E\right\}_{f_0}^{f},$$

$$\tan(E/2) = \gamma^2\tan(f/2)$$

$$K(0,2) = \frac{1}{(1-e_0^2)^{3/2}}\left\{E + e_0\sin E\right\}_{f_0}^{f}$$

$$K^*(j,1) = \left\{\frac{\sin jf}{1 - e_0\cos f}\right\}_{f_0}^{f}$$

$$K(0,1) = \frac{E - E_0}{(1-e_0^2)^{\frac{1}{2}}}$$

$$K(1,1) = -\frac{1}{e_0}\left\{f - \frac{E}{\sqrt{1-e_0^2}}\right\}_{f_0}^{f}$$

$$K(2,1) = -\frac{2}{e_0^2}\left\{\frac{f}{e_0} + \sin f - \frac{E}{e_0\sqrt{1-e_0^2}}\right\}_{f_0}^{f} - K(0,1)$$

$$K(3,1) = -\frac{4}{e_0}\left\{\frac{(2+e_0^2)}{2e_0^2}\cdot f + \frac{1}{e_0}\sin f + \frac{\sin 2f}{4} - \frac{E}{e_0^2\sqrt{1-e_0^2}}\right\}_{f_0}^{f} - 3K(1,1)$$

$$K(4,1) = -\frac{8}{e_0}\left\{\frac{(2+e_0^2)}{2e_0^3}f + \frac{(4+3e_0^2)}{4e_0^2}\sin f + \frac{1}{4e_0}\sin 2f + \frac{1}{12}\sin 3f - \frac{E}{e_0^3\sqrt{1-e_0^2}}\right\}_{f_0}^{f} - 4K(2,1) - 3K(0,1)$$

$$C = \frac{6J\delta^2}{a_0(1-e_0^2)^3}$$

$$A_0 = 0$$

$$A_1 = \frac{e_0(4+e_0^2)(3\sin^2\theta_{m0} - 2)}{8} - \frac{3e_0(4+e_0^2)\sin^2\theta_{m0}\cos 2\omega_0}{16} + \frac{e_0}{6}A_4$$

$$A_2 = -\frac{e_0^2(3\sin^2\theta_{m0} - 2)}{4} + \frac{(2+3e_0^2)\sin^2\theta_{m0}\cos 2\omega_0}{4}$$

$$A_3 = \frac{e_0^3(3\sin^2\theta_{m0} - 2)}{24} - \frac{3e_0(4+e_0^2)\sin^2\theta_{m0}\cos 2\omega_0}{16}$$

$$A_4 = \frac{3e_0^2\sin^2\theta_{m0}\cos 2\omega_0}{8}$$

$$A_5 = -\frac{e_0}{6}A_4$$

$$B_0 = 0$$

$$B_1 = B_3 - B_5$$

$$B_2 = -\frac{(2+3e_0^2)\sin^2\theta_{m0}\sin 2\omega_0}{4}$$

$$B_3 = \frac{3e_0(4+e_0^2)\sin^2\theta_{m0}\sin 2\omega_0}{16}$$

$$B_4 = -\frac{3e_0^2\sin^2\theta_{m0}\sin 2\omega_0}{8}$$

$$B_5 = -\frac{e_0}{6}B_4$$

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AN HYPOTHESIS ON THE SLOW MOVING GREEN FIREBALLS*

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ABSTRACT

The slow green fireballs are distinguished from ordinary meteors and their characteristics are described. The theory is advanced that they are cometoids, composed of matter in a physical state between those of meteoroids and comets, namely chunks of frozen substances ("ices") at very low temperatures. The matter is probably in an unstable state and contains a source of thermal and luminous energy; evidence is presented in support of the suggestion that this is solid nitrogen.

The large object which impacted in central Siberia in 1908 is believed to have been a rare retrograde cometoid; the available data on this incident are reviewed.

I. INTRODUCTION

In what follows, a theory is presented which offers an explanation for the actions of certain bizarre fireballs. By a process of analytic continuation, the results can be applied to other forms or shapes of unidentified aerial phenomena. In particular, the theory applies to sizable objects (orders of inches or feet) which slow down to speeds of a few hundred miles/hr. or less at altitudes of a few miles. Certain characteristics such as wobbling in flight, fuzziness at low altitudes or a shiny, metallic appearance at high altitudes, light emissions, short lifetimes, lack of remains, and spheroidal shapes, etc., can be predicted and explained qualitatively.

Actions of this type cannot be attributed to objects which produce the common variety of meteors and fireballs, *i.e.*, to stone or iron meteorites or dustballs (meteoroids).

The unusual meteors discussed here are believed to be caused by pieces of comets (cometoids), *i.e.*, chunks of frozen matter (ices) which are at very low temperatures. Furthermore, from what is known about comets this matter may be in an unstable physical state, containing a source of thermal and luminous energy. The thermal energy is expected to come from recombinations of frozen radicals and metastable atoms, and the light emission from atoms which radiate when dropping back to ground states, *e.g.*, metastable nitrogen.

It is suggested that a short-period cometoid stream may originate when a member of Jupiter's comet family comes too close to Jupiter. The combination of tidal actions and internal explosions could completely shatter the comet to produce myriads of small bodies ranging in diameter from inches to hundreds of feet.

Furthermore, a near-encounter with Jupiter could deflect the trajectories of the particles nearer the Sun to a point where, at one astronomical unit, the Earth would be in a position to intercept them.

The lifetime of a cometoid stream will be very short. Over 99% of it is likely to sublimate from solar radiation in a decade. The remaining large objects will be scarce and mixed in with the dust remnants. In other words, the cometoid stream will be a transient phenomenon and within a few years it will become a meteor stream. A few large cometoids may be present for a century or so. There is evidence for the presence of cometoids in the great Leonid shower of 1833.

The object which struck in Central Siberia in 1908, wiping out an estimated 80 million trees, was probably a sporadic cometoid. Although several expeditions were made to this area, meteorites were not found. Only dust, which probably constitutes 3%, or less, of the volume of cometoids, may have been found.

Because of the radial nature of a cometoid explosion, it is suggested that some of the lunar craters may have been formed by cometoid impact. For example, the Moon may have intercepted a cometoid stream on several occasions.

Impacts of small cometoids on the Moon could dislodge debris from the surface to produce a special type of stone meteorite. Urey has recently found evidence to suggest that some meteorites may have originated from the Moon.[1] It is possible that cometoids could have played a part in this. Such processes may still be going on.

A discussion of comets is presented, although very little is actually known about the comet's nucleus. However, a knowledge of the physical stage of comet nuclei is necessary in order to understand the actions of cometoids in the atmosphere.

It has been established quantitatively that a solid sphere of frozen water, entering the atmosphere at a speed of 6·9 miles/sec., can survive and slow down to terminal speeds without completely ablating.[2] The steeper the angle of entry (with the local horizontal), the greater the drag stresses but the smaller the net heat influx. A sphere of frozen water, having a radius of 1 ft., which enters the atmosphere at an angle of $-6°$ with the horizontal (84° with the vertical), loses only

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half of its radius. By the time it descends to an altitude of 100,000 ft., the speed is only 1700 miles/hr. and the frictional heating is negligible.

A sphere with a radius of 5 ft., under the same conditions, loses about 7·8 in. The ablation stops at an altitude of roughly 50,000 ft. where it is still travelling at 2000 miles/hr.

The entry of cometoids into the atmosphere is more complicated. In general, the ice matrix will be inhomogeneous, the materials with higher vapour pressures, or higher radical concentration, tending to volatilize first. The entities will therefore gradually hollow out, leaving a connected network of vesicles, or cavities. At the same time, the outer parts which have lower vapour pressures, *e.g.*, water, will tend to melt and refreeze to form a solid, glassy shell.

Gases from the interior will be heated from radical recombinations and by atmospheric oxidation. The gas temperatures will be at least as high as the temperatures found for molecular gases ejected by comets. Gas molecules have been observed[3] to leave comet nuclei with speeds of 1–3 km./sec. This corresponds, for example, to temperatures of 1000°–3000° F. (540°–1650° C.) for methane. Thus, the very cold cometoid is probably filled with very hot gases. The lifetime in the Earth's atmosphere is therefore very limited.

Several mechanisms are discussed which produce lift forces, including the hot-air balloon effect.

The emission of light can be predicted on the basis of laboratory experiments.

Finally, a discussion of the Siberian impact has been included since this appears to be an example of a large, retrograde cometoid which hit the ground.

II. UNUSUAL FIREBALLS

Fireball, as used here, applies to meteors with intensities comparable to the brighter planets. At night they produce noticeable shadows. The increased brightness is ordinarily associated with the added frictional heating, ionization and fragmentation resulting from higher speeds. For example, the von Niessl-Hoffmeister fireball catalogue lists 79% of the 611 entries as possessing hyperbolic velocities.[4] Although Fisher has shown that these velocities are overestimated they are still near the parabolic end or high end of the velocity spectrum.[5]

Brightness of objects seen visually is also associated with wavelength. That is, the eye is not equally sensitive to the different wavelengths in the visible spectrum. Under identical conditions of brightness, a yellow-green fireball radiating 5550 Å. in daylight will appear brightest to most people. However, in dim light the eye becomes more sensitive to green or blue-green light in the neighbourhood of 5050 Å. Thus the peak sensitivity shifts over a range of 500 Å., depending on ambient light intensity. It is not surprising therefore that many bright green fireballs have been seen. The common, greenish-coloured meteor tends to have a pale yellowish tint.

Size also has a direct bearing on brightness. However, in the case of the slow fireballs discussed here, energy stored in the fireball must be responsible for the light emission rather than size or speed, as such. The ability to radiate light while travelling at speeds comparable to aircraft, or less, sets these objects apart from the more common fireballs. In fact, their characteristics seemed for many years to be at variance with accepted behaviour, and observations were seriously questioned and usually omitted from scientific journals. On the other hand, these same characteristics result in such sensational and weird phenomena that they fascinate the public, and observations have always appeared in the popular press.

Many of the objects reported in older journals and books cannot logically be placed in any other known category. The sightings appear to come during a brief period of a few days, or weeks. There are some indications that semiannual or annual returns may occur for a time. Several decades may pass before another grand display. Sporadic sightings are also observed. During July and August in 1952 the U.S. Air Force investigated hordes of unidentified flying objects.[6]

Analysis of fireball observations permits us to distinguish between ordinary fireballs and the type discussed here. An ordinary fireball will usually burn out at an altitude between 25 and 125 miles. The rarer varieties, caused by meteorites, will often reach low altitudes of 10 or 15 miles where they may drop meteorites to the ground, or land intact.

The slow, green fireballs seem to display a variety of novel characteristics. Some of these are listed below.

Brightness.—They appear too bright for their speeds to attribute the intensity to incandescence or to excited states in the stagnation region. Aeroplane pilots have observed "blinding" lights from large, slow objects.

Colour.—The colour of the bright green objects is often a shade of green near 5200 Å. or more. A red halo or red tint has occasionally been observed in the wake. At least one object ended its flight in a silent green flash of light. The nuclei are usually enveloped in a coma which has the shape of a green teardrop or flame.

Size.—They often appear to be quite large, of the order of a few feet to many feet in diameter.

Trajectories.—The flight paths below a few thousand feet in altitude have appeared to be roughly horizontal, indicating some kind of a lift mechanism.

Flight Characteristics.—They have been observed to change course or have an erratic flight path. The altitudes are often less than a few thousand feet although they are rarely accompanied by audible sounds or shocks.

Material Evidence.—Careful searches of areas where flights terminated or where the objects should have hit the ground have never revealed debris of any kind. Falling droplets have been seen after the passage of a fireball.[7]

Up to now there has not been an adequate explanation of these phenomena.

III. BACKGROUND

In 1803, the French Academy of Science was finally convinced, after years of resistance, that meteorites were extraterrestrial (not atmospheric). Biot made a detailed study of some stones that fell out of the sky at L'Aigle, in Normandy, and concluded to the academy's satisfaction that they did indeed fall from the surrounding space.

Prior to the eighteenth century, meteors were believed to be meteorological phenomena such as atmospheric manifestations. Consequently, learned people were not particularly prejudiced against slow moving objects, not knowing what caused them. Even stationary meteors were reported.

General acceptance of the new dogma that meteors were caused by solid, high-density materials such as pieces of stone or iron, made observations of slow or stationary meteors appear ridiculous. The reasoning ran something like this. It was known from Newton's law of gravitation that extraterrestrial objects enter the atmosphere with speeds of at least 6·9 miles/sec. Furthermore, it was observed that the majority of meteors travelled at speeds of 20 to 30 miles/sec. Also, except for dust particles and very special shapes, the atmosphere is not capable of slowing such dense objects down to speeds of a few hundred miles/hr. Finally, even if this did happen, they would be falling almost vertically at terminal velocities, and at these speeds the frictional heating would be inadequate to produce incandescence, or even luminous trails.

For these reasons and others, observations of slow moving bright fireballs have been seriously questioned and generally omitted from scientific journals, especially in recent years.

Many older observations can be found. For example, W. F. Denning[8] described a slow meteor which took at least 15 sec. to cross the sky.

One textbook, which was written in 1869 and used in colleges for some 50 years (the eighth edition was printed in 1920) still retained an interesting observation in the eighth edition.[9] The sighting occurred during the great Leonid meteor shower of 12 November, 1833, which is the most remarkable shower on record. At certain places the meteor density was of the order of 200,000 observable meteors/hr. from a single station.

During this shower certain bizarre objects, moving too slowly to be conventional meteors, were observed. To quote from p. 229 of White and Blackburn,[9] "An observer at Boston about 6.00 a.m. counted 650 shooting stars in a quarter of an hour. Large fireballs with luminous trains were also seen, some of which remained visible for several minutes. Even *stationary masses* of *luminous matter* are said to have been seen and one in particular is mentioned as having remained for some time in the zenith over the falls of Niagara, emitting radiant streams of light." Evidently, if this had occurred in the last decade, it would have been classified as an unidentified flying object (UFO). The nature of this luminous matter, apparently associated with the meteor shower, is of considerable interest. The question that arises then, is this: what kind of objects besides ordinary meteors might be present during a meteor shower?

IV. METEORS

The word *meteor* is derived from the Latin and Greek meaning "thing in the air." It is used here in reference to the light phenomena which occur when an extraterrestrial object falls into the atmosphere. It is now generally recognized that meteors result from two distinct classes of materials, meteorites and meteoroids. The *meteorites* are the hard, solid, high-density materials which occasionally hit the ground. The *meteoroids* as defined by Whipple have just the opposite characteristics, *i.e.*, they are fragile, porous materials that always seem to ablate high in the sky.[10] Almost all of the visual meteors which appear in the atmosphere each day (about 200 million) are caused by meteoroids, whereas meteorites are extremely rare.

This significant change in our concepts of ordinary meteors has occurred within the last few years. It was brought about by the Harvard Photographic Meteor Programme and substantiated in part by radar studies. According to Whipple,[11] the following deductions have been substantiated for the meteors photographed in their programme:

(1) Practically all are of cometary origin (meteoroids).

(2) Asteroidal meteors are very scarce if present at all.

(3) There are strong indications that the meteoroids have densities of the order of 0·05 g./cm.^{3} (about one-fourth the density of balsa wood).

(4) They appear to be extremely fragile.

(5) Meteoroids which have a common origin from a known comet tend statistically to be more alike with respect to fragility, composition, density, luminous and ionizing efficiency.

Therefore, with few exceptions, meteors are caused by extremely fragile, porous objects which probably originate from comets. In some instances meteor streams have been definitely connected with comets. For example, there are four permanent annual cometary showers (Lyrids, Aquarids of May, Orionids and the Leonids). Some evidence suggests that the Orionids and Aquarids of May are the same current encountered twice at different points along the Earth's orbit, *i.e.*, the maxima occur at times of closest approach of the Earth to the orbit of Halley's comet. There are also several temporary streams known to be associated with short period comets. For example, the Draconids of June follow the orbit of Pons-Winnecke. Finally there are many sporadic meteors which have not been tied in with any known stream or comet.

However, neither meteorites nor meteoroids, as ordinarily conceived, can possibly produce the characteristics of the slow fireballs. It is logical therefore to look for another possible component in the meteor

streams besides dustballs, or meteoroids. Since some streams are associated with comets it is expedient to begin with comets.

V. THE COMET—NATURE'S SOLAR PROBE

The solar system is surrounded by a vast spherically-shaped cloud of comets which must extend out to about 150,000 A.U. (astronomical units). The cloud is expected to contain 10^{11} objects of observable size.[12] At such great distances from the Sun the nuclei would have temperatures of a few degrees above absolute zero. Under these conditions the frozen nuclei would not suffer attrition from sublimation by solar heating.

The motivating forces which occasionally cause some of these entities to fall towards the Sun are supplied by passing stars which effectively reshuffle the velocity distributions every few million years.

A small number of these objects which are moving in long-period orbits, have a probability of being captured by the planet Jupiter. When this happens they are gradually brought down into short-period orbits. There are about 75 known comets with periods less than 100 years. Jupiter, more than any other planet, plays the leading role in capturing these objects and, indeed, they are known as Jupiter's family of comets. All of them have direct orbits, except for Halley's comet. The average absolute inclination to Jupiter's orbital plane is about 13°.

1. The Composition of Nuclei

The physical nature of comets has remained a mystery since the beginning of astronomy. Their origin, which appears to be relatively recent compared to the rest of the solar system, is also baffling. For example, their masses are not high enough to suggest a formation by gravitational accretion. Also the majority of nuclei, when visible, are in a peculiar state of disintegration and cannot be recognized by appearance alone. Furthermore, they have been observed to emit intense light, pass in and out of the Sun's corona, break into pieces, explode violently, speed up or slow down in their orbits, and occasionally vanish altogether or never return. Indeed, the comet is the "flying saucer" or UFO of astronomy.

It was believed quite generally, until the last decade, that comets were flying gravel banks, the gravel consisting of hard, solid, high-density materials called meteorites. In other words, they were composed of materials similar to the stony or iron-nickel objects sometimes found on the ground. The gravel bank hypothesis was useful for it seemed to explain several strange characteristics of comets: (1) the scarcity of phases in comets; (2) the absence of star occultations by any part of a comet; (3) the complete vanishing of the nuclei when the Sun was eclipsed; (4) the surprisingly large amounts of occluded gas liberated from the meteorite material (because of the large exposed surface in a gravel bank); and (5) the low masses of the nuclei.

However, the gravel bank hypothesis has several weak points. Many of the comets which have passed close to the Sun or Jupiter in the past, and remained intact, would have fallen apart or disrupted from the gravitational tidal forces. Also, the gases released during close passages to the Sun would tend to start the array diverging. According to Bobrovnikov,[13] every metallic object less than 1 ft. in diameter would have been vaporized during the perihelion passage of the great comet of 1882 II. This can be increased to about 4 ft. for an ice gravel. This not only would have created a significant amount of gas, but should have practically destroyed the gravel bank. No such effect was observed. Furthermore, not once during any meteor shower, known to be associated with a comet, has a meteorite been observed to fall which could be attributed to the shower.

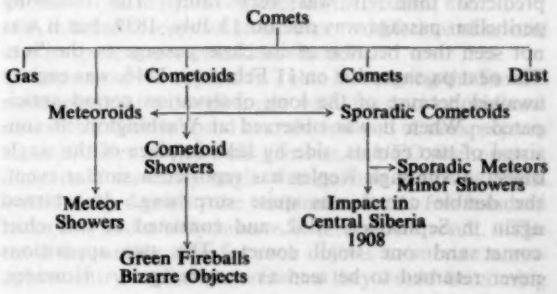
Actually all five of the preceding observations can be explained if the nuclei are assumed to be small, single entities composed of *ices* (frozen gases). The *ices* referred to here are unknown compounds or radicals involving the elements hydrogen, oxygen, nitrogen, and carbon. Most of the more probable species would have melting points, under atmospheric pressure, of less than several hundred degrees absolute.[14]

A small amount of siliceous and metallic dust, in microscopic sizes, is also expected to be present. Meteorites, *per se*, are highly unlikely to be found in comets. It is not impossible, however, even if all meteorites originated from the asteroid belt. The reason is that the massive planet Jupiter is capable of ejecting asteroidal matter out to the cometary cloud region and beyond. Thus there could be ice bodies in the cloud of comets which contain imbedded meteorites.

2. Disintegration Products

In general, all comets having a coma and tail are in a state of disintegration. An outline of the immediate products of disintegration is given in Table I. Gases in the molecular, radical, atomic and ionized state are known to exist in the head (the head consists of the coma and nucleus taken together). Dust is believed to evolve from nuclei since light is scattered from solid particles in the heads and tails, and meteor showers have occurred after the passage of the Earth through a region previously occupied by a comet.

TABLE I.



The word *meteoroid* was coined by Whipple to describe the dust aggregates which are sloughed from the surfaces of comet nuclei after a stratum of ice has evaporated. Most of the 200 million naked-eye meteors that the Earth receives each day are of this type.[15]

The word *cometoid* has been introduced here to account for cometary matter which is in a physical state between meteoroids and comets, namely, chunks of ice too small to produce observable comets.

A few comets which were accessible to observation have been seen to disintegrate or break up when near the Sun or after having passed close to Jupiter. Others have been observed to throw out luminous pieces of matter. Materials in this class have been completely neglected in discussions pertaining to meteors, although there are logical reasons to assume that comets, with ice nuclei, will occasionally eject sizable chunks of matter. For example, this could result from the tidal actions of Jupiter, by internal "boiler" type explosions, as suggested by Whitney (but on a smaller scale) in connection with comet outbreaks, or by chemical explosions of the type discussed by Urey.[16]

Some comets have been observed to break into two parts, each large enough to carry on as an individual comet. Brooks 2 split into five parts in 1889. The bright comets 1668 , 1843 I, 1880 I, 1882 II, and 1887 I all move in similar orbits and probably resulted from the decomposition of a single body. Each one of these objects was brighter and presumably more massive than Halley's comet. Comet 1882 II showed signs of additional disintegration following perihelion, as many bright bodies (cometoids) were reported in its vicinity.

Browning observed a magnificent fireball on 13 October, 1873, and was able to identify, by direct comparison, the spectrum of a hydrocarbon (methane). Observations of this type suggest cometoid fireballs.[17]

Biela's comet is an interesting example of comet breakup. On 27 February, 1826, an Austrian army officer named Biela, discovered a faint comet which was destined to bear his name. Its orbit was studied for several weeks and it was finally identified as the same comet which appeared in 1772 and in 1805. Santini found its period to be 2455 days and predicted that the attractions of the Earth, Jupiter and Saturn would cause it to return 10 days sooner. The comet returned to perihelion in November, 1832, within 12 hr. of the predicted time. It was very faint. The following perihelion passage was due on 13 July, 1839, but it was not seen then because of its close passage to the Sun. The next passage, due on 11 February, 1846, was eagerly awaited because of the long observation period anticipated. When it was observed at Washington, it consisted of two comets, side by side, in place of the single object. Although Kepler has reported a similar event, the double comet was quite surprising. It returned again in September, 1852, and consisted of one chief comet and one small comet. The two apparitions never returned to be seen as comets again. However, on 27 November, 1872, when the Earth passed through the comet's orbit, a fine meteor shower occurred, but these meteors were caused by meteoroids released from the comet at a much earlier stage in its evolution. The cometoids, if such objects were formed, probably missed the Earth. If cometoids had been present they would have tended to slow down to low speeds and exhibit behaviour entirely different from that of the meteoroids.

The fact that comets are able to eject sizable fragments suggests that the masses of comets are small and that their own gravity is on the verge of being too feeble to hold their nuclei together.

The chances of the Earth encountering a sizable ice body during a meteor shower is small because of the limited lifetime of ice in comparison to the lifetime of meteoroids. However, the phenomenon observed during the meteor shower of 1833 could have been caused by such materials.

3. Cometoid Sources

Bright comets are recognized by their immense tails and characteristic heads. However, the average comet is not even visible to the naked eye. Furthermore, it may lack any evidence of a tail and the coma may be very faint. When far from the Sun the nucleus may take on a stellar appearance and be indistinguisable from an asteroid. More likely than not it is too small to be detected. Consequently comets with perihelia of the order of two or more astronominal units are often overlooked. Sometimes they pass by unnoticed even when their orbital elements are known. Furthermore, from probability, there should be many more comets with perihelia lying between Mars and Saturn, for example, than between Mars and the Sun. This applies to both short-period and long-period comets. Thus a number of disruptions, possibly a dozen per century, may occur near Jupiter. Because of the lack of a noticeable coma or tail at this distance, the dismemberment is apt to be inaccessible to observation.

The most favourable circumstances occur when Jupiter perturbs a short-period comet, with an aphelion distance of six or more astronomical units, and attracts it in close enough to achieve a complete disruption. If the cometoids produced under these conditions have perihelia of the order of one astronomical unit, and if the orbital inclination to the ecliptic plane is small, then the Earth is in an excellent position to capture the ice debris. It is assumed, of course, that the short period comet is in a direct orbit.

The probability of an event of this type occurring is not known. In order for the Earth to intercept these ice entities it is required that both the Earth and the fragments be close to the intersection, or nodal point, simultaneously. The stream will gradually deteriorate by sublimation. The dust which remains behind will have a much longer lifetime. Thus, unless the Earth intersects the stream during the first few years of its existence, the

chances of a large chunk of ice entering the atmosphere are small. Most or all of the meteors during regular meteor showers are undoubtedly of the dustball variety.

4. Size-Frequency Distributions for Cometoids

The comet in general is a complicated object capable of exploding. It is therefore not possible to give a strictly quantitative formula for the distribution of sizes following a disruption by tidal action. However, a rough idea of what could occur can be obtained by one or two hypothetical cases. Suppose that we take a small faint comet with a radius of 1000 m. If this object divided into small spheres, each having a radius of 1 m. (3·28 ft.) there would be 10^9 of them. A more realistic distribution might be obtained by assuming that the number-mass distribution is similar to that found for meteoroids. This is done in Table II, where it is

Table II.—*Initial Data—Comet Radius: 1000 m.; Comet Density: 0.5g./cm³.; Comet Mass: 4.2 × 10^{15}g.*

Number	Radius		Total mass, g.
	m.	ft.	
1	464	1522	$4·2 \times 10^{14}$
10	215	695	$4·2 \times 10^{14}$
100	100	328	$4·2 \times 10^{14}$
1000	46·4	152	$4·2 \times 10^{14}$
10,000	21·5	69·5	$4·2 \times 10^{14}$
100,000	10·0	32·8	$4·2 \times 10^{14}$
1,000,000	4·64	15·2	$4·2 \times 10^{14}$
10,000,000	2·15	7·0	$4·2 \times 10^{14}$
100,000,000	1·0	3·3	$4·2 \times 10^{14}$
1,000,000,000	0·464	1·5	$4·2 \times 10^{14}$

assumed that the densities are constant. The sizes range from 3 to 3000 ft. in diameter. Some of the larger pieces might still appear as faint comets if they became positioned favourably with respect to the Earth. Actually the sizes of nuclei are not well established. Halley's comet vanished in front of the Sun and could not have exceeded 70 km. in diameter. The great comet of 1841 I observed by H. Struve and O. Struve must have had a diameter of 100 km. or more. Clearly, a larger comet would be capable of producing myriads of small entities as well as many cometary-size objects.

5. Lifetime of Cometoids

The lifetime of ice chunks in short-period orbits will not be unlimited. Based on our knowledge of comets, the probable lifetime of cometoids may be calculated. Arguments by Whipple[14] and others have demonstrated that nuclei, in general, are extremely poor thermal conductors. It follows therefore that the rate of sublimation is approximately independent of the radius. Small spheres of ice will consequently tend to lose the same increment from their radii as large spheres or comets, assuming that they have identical environments and similar compositions. The lifetime of a comet with radius 1 km., which has a perihelion distance of 1 A.U., is of the order of 1000–10,000 years. This corresponds to a loss in radius of 10–100 cm./year on the average. Thus the 10^9 smaller pieces, with a 50-cm. initial radius from Table II, would completely sublimate after an exposure of 6 months to about 5 years. Another hundred million objects with an initial diameter of 6·6 ft. will have sublimated (leaving only dust structures) after a period of 1–10 years. The largest object should last from 500 to 1000 years. The conservative picture of a 1000-year lifetime for the parent comet is probably more realistic. The lifetime of the fragments in Table II, expressed in years, is then numerically equal to the radius in metres. That is, an object with a diameter of 304 ft. or a radius of 46·4 m. would take 46·4 years to sublimate. Thus, with the passage of time following disruption larger-diameter cometoids gradually become numerically predominant. This is shown in Table III,

Table III

Time duration, years	Number	Most abundant diameter,	
		m.	ft.
Breakup	1,000,000,000	1	3·28
0·46	100,000,000	1·08	3·51
1·0	10,000,000	2·3	7·55
2·15	1,000,000	4·98	16·3
4·64	100,000	10·1	33·1
10·0	10,000	23·0	75·5
21·5	1000	49·8	163·5
46·4	100	107·2	351
100	10	230	755
215	1	498	1635

where, *e.g.*, after 4·6 years, 99·99% have vanished and of the remainder, the most numerous have diameters of at least 10·7 m. (35·1 ft.). Thus, with the assumed distribution, if the Earth intersected a new cometoid stream, there would be a great numer of small fireballs observed during the first encounter. Some years later, far fewer objects would be observed, but they would be relatively large. Finally, only one, the largest, could be seen. The most important observation is that the numerous small objects, of the order of a few feet, would tend to be wiped out in a year or two. Of course, this is highly qualitative, because many other factors enter in, *e.g.*, orbital eccentricity, divergence of the stream, etc.

A detailed discussion of the expected lifetime of several ices in space is presented elsewhere.[18]

Any one of the objects, in Table II, entering the Earth's atmosphere at a small angle with the local horizontal and with a relative speed near the low end of the spectrum (9 to 10 miles/sec.), would give rise to UFO phenomena. That is, if the entry angle was not too steep the speed would drop down to the terminal value (a few hundred miles/hr.) and a truly bizarre meteor would result. The most favourable time for such objects to survive atmosphere entry is after sunset when they would be coming

up from behind the Earth and the angular velocity of the atmosphere would be in the right direction to make the drag stresses less severe.

VI. PHYSICAL PHENOMENA ACCOMPANYING COMETOID ENTRY INTO THE ATMOSPHERE

The entry of large bodies into the Earth's atmosphere can be analyzed[19] by present-day theory for speeds up to Mach 59 or about 10 miles/sec. This is more than 3 miles/sec. faster than the entry velocity of the slowest meteors and therefore of great value in this investigation.

With knowledge of the drag and heat transfer rate, the question of the survival time and sublimation rate of cometoids can be answered quantitatively. The basic equations along with many trajectories and sublimation rates, are presented in another paper.[2]

At this time we are interested in examining the processes taking place within a spherical cometoid which is rotating about an axis whose direction is changing randomly. The implications are that over a short period of time, the heat transferred per unit area will be approximately the same over any portion of the surface. Also this picture is in tune with assumptions made in arriving at the equation for heat influx (Equation (A.1); see Appendix A).

However, it is evident that if the object had been only approximately spherical prior to entry (*e.g.*, a cube), then the erosive action of the atmosphere would tend to make it spherical. For example, the corners might become turbulence centres, or stagnation points, and they would tend to become rounded. The edges would also be more susceptible to ablation than the flat sides.

This weathering action, combined with the added violence from radical recombinations, will tend to produce bodies of revolution, in general. In particular, depending on the initial configuration such shapes as spheres, discs, and cigars, etc., would be expected.

Returning now to the sphere, it is of interest to see what action may take place as it penetrates the Earth's upper atmosphere. Bodies which are captured by the Earth at speeds near the lowest possible limit will tend to have small entry angles with the local horizontal. Steep angles are not impossible but more improbable. The object which impacted in Siberia in 1908 may have had a steep entry angle. Because this fantastic event may have been caused by an ice meteorite of the type that we are considering, a separate section has been devoted to it.

With smaller entry angles, the net energy transferred by the time the speed has been reduced to Mach 0·5 may be considerably greater than for steeper angles, although the decelerations are more gentle. The crushing compressive stresses associated with steeper entry angles are more damaging, indirectly, than the thermal influx. That is to say, once the parent body is broken into numerous fragments, the real damage has been done, for then the heat influx affects each piece individually. Everything may then be quickly destroyed. For example, from Equation (A.1), if the fragments had the same speed as the parent body, the heat influx per unit area would be increased by $1/\sqrt{a}$, where a is the radius. Thus, a fragment with a radius of 1 in. decreases in radius ten times as fast as a parent body with a 100-in. radius. It follows that if a large cometoid can stay together through the high stress periods it will descend to low altitudes where it may produce unusual aerial phenomena and be classed as an unidentified flying object. Its speed may drop to a few miles/hr. or even to zero, while simultaneously it may be luminescent. The often heard comment that "it is going too slowly to be a meteor" is no longer justified since luminous ices in the atmosphere can be classified as meteors. Furthermore, it will be shown subsequently, that a small concentration of frozen metastable nitrogen atoms in an ice matrix, can indeed produce a brilliant light when the ice is ablating under the proper conditions.

1. Formation of Spheroidal Shapes by Ablation

A cometoid in general is a heterogeneous mixture. In space, the outer covering will contain only dust, and ices which have low vapour pressures such as water, resinous and wax-like materials. The internal parts will remain extremely cold and could contain materials which would be very volatile in the Earth's atmosphere, *e.g.*, methane or ethylene.

Upon entering the atmosphere at high altitude, a cometoid will lose its protective dust cover and start eroding and sublimating. A type of erosion caused by radical recombinations could continually produce groups of hot molecules. These molecules would be ejected at the corresponding thermal velocities. When recombinations occurred, neighbouring molecules could also be dislodged (sublimated) and lost to the ice matrix, but, fortunately, most of the recombination energy will go into the kinetic energy of ejected gas. The cometoid therefore need not be destroyed by its own internal energy. Also, the ejected vapour will act as a transpiration cooling agent, tending to cut the convected heat transfer by as much as 50%.

During this period when the pressure is inadequate to produce melting, the cometoid will undergo a preliminary shaping by the aforementioned ablation processes. Corners will be removed, sharp edges dulled and rounded, and the surface pitted.

Heterogeneous ices in the matrix will keep the entity turning. It is most improbable that the tangential components of the gas jets would be exactly balanced at all times. It does not matter whether the cometoid always turns in one direction or rocks back and forth, as long as it keeps exposing different parts of the surface to the stagnation region, the rounding and forming process will continue.

A macroscopic radical explosion, such as a chain reaction between many radicals, of course, can destroy the entity altogether. However, the heat transferred

through the surface, from pinpoint explosions on the surface, is assumed to be negligible. The presence of silicate and metallic dust grains plus inert molecules, can suffice to damp explosive chain reactions of this type.

The temperature of the ice is not expected to change significantly during this period. The sublimation of volatile constituents will keep the temperature low. Also, the ices are expected to be poor thermal conductors.[14]

At lower altitudes, the pressure will be high enough to produce melting. The instantaneous pressure differential between the fore and aft stagnation points will tend to force portions of the surface, which melt when turning through the forward stagnation point, to flow into the underlying cracks and crannies. The liquids will also spread a short distance on the surface.

The melting and refreezing process is apt to take place quickly, especially for objects which are turning rapidly. Substances like water, which expand on freezing, can melt under pressure and refreeze when the pressure is removed provided the temperature is not too low. Liquids which ooze into the substrata will tend to sublimate the more volatile materials while freezing themselves. By this process a shell of low-vapour-pressure ice is expected to form around the cometoid. It might have a shiny glassy appearance if it could be broken off and examined. The shiny, metallic appearance reported for many "flying saucers" might be caused by reflections from a slick ice surface. The shell, which would contain tiny pores, will protect the more fragile substrata, which at this stage are porous but tending to be more solid towards the centre. This might also result in bands or markings of melted material around the sphere. If the whole sphere were not covered it would look like a ball of ribbon.

A spinning disc could leave concentric stripes, or a cigar-shaped object spinning about its longitudinal axis (with this axis pointing in the direction of flight so as not to break in half) might have a series of bands, etc. If the melted ices were of a different colour than the rest of the matrix, the stripes could be very noticeable. The imbedded dust could add colouring.

2. Natural Life Mechanisms

Since the majority of the ices expected in cometoids cannot exist at temperatures much above a hundred degrees Kelvin, it follows that these objects must be quite cold as long as they exist. Even ordinary water ice would remain at 273° K. or less. Hence, during the disintegration period, cometoids in general may have very cold ice structures which are filled with hot gases. These gases, being in a state of flux, will shoot out through the various openings in the shell to produce a miniature coma. Cometoids which consist of inhomogeneous ices, in general then, will hollow out, and become more like hot-air balloons.

Also, because of radical recombinations and sublimation, or melting and evaporation at the forward stagnation point, small jets tending to oppose the body's motion will occur. Actually, the reactions will not occur instantaneously, so that a sphere tumbling randomly will have a path through the sky which is slightly erratic. A disc-shaped body, spinning clockwise about a vertical axis, would make a gradual counterclockwise turn.

If a jet occurred from the interior through just one opening in the shell or if one of several jets predominated, the sphere or disc would wobble in flight.

Only a small fraction of the cometoids that enter the atmosphere can remain intact. Of course, one large object could yield several smaller bodies. The "survival of the fittest" concept applies here. Only those objects which have a certain structural integrity can last long enough to reach low altitudes where they would exist for a limited time.

One requirement for a sphere is that it be spinning about an axis perpendicular to the plane of the trajectory. A sphere, *per se*, has no lift, but one that is spinning and blowing out gas jets can have a lift coefficient. Referring to Fig. 1, if the sphere is spinning counterclockwise

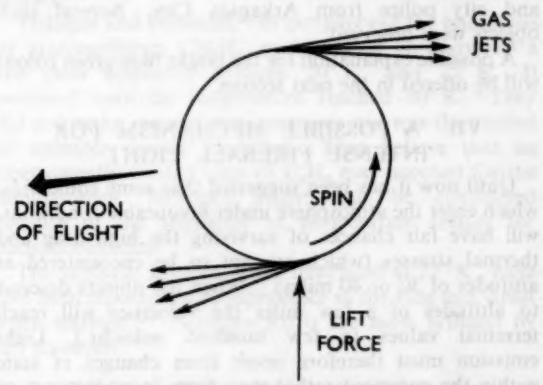


Fig. 1. How a sphere, spinning because of tangential gas jets, experiences a lift coefficient

because of a tangential gas jet, then the jet will oppose the air stream underneath so as to build up an excess pressure relative to the jets on top. This tends to produce a lifting force. If the sphere was spinning in the opposite direction it would tend to dive down into the atmosphere where the crushing drag forces would break it apart.

The tendency for the sphere to carry air with it as it spins, like a spinning baseball, would not overshadow the jets. If it did, the sphere would dive down, and the lift would have to be attributed to lift from a clockwise spin. This is unlikely because the objects probably will not be spinning so fast.

There is another lift mechanism that might apply. If some of the internal ices are melting there will be a tendency for the liquid to extrude out the bottom through any holes that are available. Internal pressures will not push liquids out of the top portion since they would be held away because of gravity. "Centrifugal forces" are probably inadequate to accomplish this. The

instant the liquid touches the atmosphere (which would be relatively hot) it might expand to create a continuous pressure underneath. For example, a small quantity of liquid methane continually oozing out of the bottom would react violently when it touched the air, expanding and exerting pressure on the bottom. Less volatile liquids might also stream out.

The following incident (taken from the *San Diego Evening Tribune*) which occurred on 19 July, 1956, in Arkansas City, Kansas, seems to be an example of a cometoid:

> "The Kansas State Highway Patrol today said 'a ball of fire travelling east at a high rate of speed had been picked up by radar at the Hutchinson (Kan.) Naval Air Station.' City Editor, Brian Coyne, of the *Arkansas City Daily Traveler* said 'a brilliantly-lighted, tear-shaped object with prongs or streams of light spraying downward was sighted shortly after midnight. A second object was sighted around 1 a.m. The prongs or streams of bright light also were observed first as directed towards the Earth and then extending from the sides of the object.' He also described the head of the object as being green in color or 'bluish green.'"

Mr. Coyne was accompanied by a Trooper Dick Hadsall and city police from Arkansas City. Several such objects were observed.

A possible explanation for the bright blue-green colour will be offered in the next section.

VII. A POSSIBLE MECHANISM FOR INTENSE FIREBALL LIGHT

Until now it has been suggested that some cometoids, which enter the atmosphere under favourable conditions, will have fair chances of surviving the high drag and thermal stresses (which are apt to be encountered at altitudes of 30 or 40 miles). When the objects descend to altitudes of a few miles the velocities will reach terminal values (a few hundred miles/hr.). Light emission must therefore result from changes of state within the cometoid rather than from incandescence or excitation of the air. Otherwise jet planes, which sometimes travel at even higher speeds, would be luminous.

It is suggested that those cometoids which are fresh from the very cold sub-surface regions of comets may at times contain dormant metastable states which are capable of emitting light when sufficiently warmed. Since comets, in general, consist principally of unknown combinations of hydrogen, nitrogen, oxygen and carbon, the metastable materials would have to be formed from one or more of these elements.

There are several procedures that can be used in the laboratory in order to discover thermo-luminescent ices. One technique is to freeze the material at liquid helium temperatures in a vacuum. The resulting ice can then be bombarded with X-rays or electrons, etc., and sometimes decomposed into radicals or metastable atoms which may exist indefinitely at low temperatures. By allowing the resulting ice to warm up, radical recombinations may occur giving off heat. Also the metastable atoms may drop their excess energy by radiating. For the last three years a great deal of frozen radical research work has been going on, especially at the National Bureau of Standards. Hundreds of different materials have been studied which are composed entirely of elements known to be abundant in comets.

However, only a handful of ices have been found which phosphoresce significantly on warm-up. Only one is exceptional and this has been known for almost 40 years. This ice is frozen nitrogen, an element quite abundant in comets.

1. Luminescence of Solid Nitrogen

Many years ago Vegard[20] bombarded solid nitrogen, at liquid helium temperatures, with a stream of electrons (cathode rays) and obtained a brilliant green glow. It was also discovered that a blue-green phosphorescence remained for as long as 5 min. following excitation. Vegard believed that a typical auroral spectrum was emitted from solid nitrogen. Later, McLennan and Shrum[21] independently discovered the green luminescence from solid nitrogen and an additional phosphorescence from argon. The latter, however, never lasted for more than a few seconds. Their results can be summarized as follows:

(1) The spectrum of solid nitrogen, phosphorescing at the temperature of liquid hydrogen, consisted of the single wavelength 5231 Å., in approximate agreement with Vegard's 5230 Å.; and

(2) The spectrum of solid argon phosphorescing at the same low temperature consisted of a strong line at 4750 Å. and a weak line at 5300 Å. It was mentioned that nitrogen underwent a transition at 35·5° K. and changes from a transparent ice to a stable powdery form. The phosphorescent energy did not exist in the stable modification.

About 30 years after the pioneer work of Vegard and others, Broida and Pellum,[22] while freezing out the products of an electrodeless discharge through nitrogen gas, rediscovered the green glow. It came from the nitrogen ice on a cold wall at 4·2° K. Since it was known that atomic nitrogen could exist in concentrations up to several per cent. in travelling from the discharge region to the cold wall, they advanced the hypothesis that the green glow was associated with the presence of free nitrogen atoms in the solid matrix.

The emission spectra were also studied by Herzfeld and Broida,[23] who were able to explain many of the results by assuming that large numbers of nitrogen atoms, in various excited states, were deposited along with nitrogen molecules from the discharge. The latest laboratory work by Peyron and Broida[24] has yielded the most accurate data on the nitrogen warm-up and afterglows available at this time.

Their experimental procedure consisted of passing various gases through a needle valve into an electrodeless discharge (2450 Mc./sec.) at a pressure of 1000 microns. The discharge products were condensed on a Pyrex glass surface, maintained at 1·2° K. by pumping on liquid helium.

When both the discharge and flow of gas are stopped, the solid deposit was found to glow deep green for several minutes. The half-life was influenced by impurities in the nitrogen, being 37 sec. for pure nitrogen and 20 sec. for nitrogen contaminated with oxygen. This phosphorescence following the discharge is called the *afterglow*. The spectrum of the afterglow shows only α, α', and α'' lines. The α lines are blue-green, while α' and α'' are single lines at 5943·8 Å. and 4683 Å. respectively.

When the afterglow has ceased, the dark solid can be made to phosphoresce at a later time by removing the helium and allowing the ice to warm up. Somewhere between 10° K. and 16° K., the α emission is observed. This consists of five lines between 5214 Å. and 5240 Å. This is followed shortly by β emission (5549 Å., 5616 Å. and 5657 Å.). These lines increase in intensity and reach a maximum near 30° K. The B band emission (3000 Å. to 4700 Å.) begins just a few degrees below this, thereby adding a blue cast to the glow. They are enhanced when a small amount of oxygen is present. It seems to last longer than the green components so that between 35° K. and 40° K. the glow is predominantly blue. There appears to be no emission above 40° K. The Vegard-Kaplan bands (2300 Å. to 4450 Å.) are also seen during warm-up when an excess of argon is deposited with the nitrogen, and oxygen is less than 0·01%.

The α lines are believed to be caused by the forbidden $2d$—$4s$ transition of atomic nitrogen. The β group may be caused by the $1s$—$1d$ transition of atomic oxygen. The B band system is not thoroughly understood. It is believed to be associated with NO_2.

Some estimated intensities of the various emissions during warm-up are presented in Table IV.

TABLE IV

Wavelength angstroms	Intense feature	System	Colour
2946	250	VK	Ultra-violet
4306	60	B	Violet-blue
4683	10	α''	Blue
5214	200	α	Blue-green
5220	500	α	
5228·5	1000	α	
5235	750	α	
5240	400	α	
5549	1000	β	Yellow
5616	750	β	
5657	650	β	
5943·8	150	α'	Orange

The relative light intensities are for a particularly good warm-up. In pure nitrogen the 5228·5 Å. line is the brightest during this period. In a very thin deposit, the green glow can be seen in daylight. The rate at which the material sublimes is very low. A fireball, consisting of a small percentage of nitrogen atoms equivalent to that responsible for the warm-up glow, would be several order of magnitude brighter because of the more rapid sublimation rate. The increased brightness has been observed in the laboratory. Herzfeld and Bass[25] state that when the phosphorescing solid was warmed suddenly from 4·2° K. to over 25° K., "it emitted a flash of blue light, which looked like a *flame burning* through the solid." This is how a cometoid fireball might appear but on a grand scale. The light would contain strong α and β components in the blue-green and yellow, and possibly enhanced B bands from oxygen impurities. The light of the fireball might therefore contain the strong lines in Table IV. There could also be infra-red lines which are not listed (7910 Å. and 8570 Å.). From many descriptions of green fireballs over New Mexico, it appears that the α lines come as close to the correct shade of green as can be expected, especially the bright 5228·5 Å. line. For instance, compare the painting by Mrs. La Paz in *Life* magazine where she tried to faithfully reproduce the actual colour of a green fireball with the cover of *Scientific American* where a photograph of the green nitrogen glow is shown.[26,27]

Milligan and Pimental,[28] in carrying out the photolysis of diazomethane, CN_2H_2, noticed that on warm-up a red glow appeared between 20° K. and 25° K. It persisted until the temperature reached 30° K. They did not make spectral measurements nor was the excited or unstable species identified. They believe that an electronically excited state of C_2H_4 may account for the luminescence. Nitrogen might also be considered because of the similarity of temperature ranges for phosphorescence.

The aliphatic ketones, when irradiated at 77° K., have also been reported to phosphoresce in the blue and violet when warmed.[25] Nitrogen ice is the most brilliant by far, however.

2. Estimated Brightness of Phosphorescing Fireballs

Consider a sphere of frozen nitrogen which contains a small percentage of metastable nitrogen atoms, comparable to that currently achievable in the laboratory.

If n is the number of pairs of frozen atoms per N molecules, then the unstable percentage, P_r, is given by

$$P_r = \frac{100\,n}{N+n} \quad .. \quad .. \quad (1)$$

and

$$n = \frac{N\,P_r}{100-P_r} \quad .. \quad .. \quad (2)$$

Similarly, if m is the mass of a nitrogen atom, then the mass of the unstable matter is given by $2nm$, or from Equation (2),

$$2nm = \frac{2\,Nm\,P_r}{100-P_r} \quad .. \quad .. \quad (3)$$

The mass of the nitrogen sphere, M, is given by

$$M = 2(N+n)\mathrm{m} = \tfrac{4}{3}\pi\rho a^3 \quad .. \quad .. \quad (4)$$

where ρ is the density of solid nitrogen.

Thus if $\dot{M}$ g. are sublimated from the sphere per second, then the corresponding mass of reactive atoms in $\dot{M}$ is $n\dot{M}/(n+M)$ or $\dot{M}\,P_r/100$. This is equal to $\dot{M}\,P_r/100m$ atoms/sec., or if all the atoms recombine to form molecules, $\dot{M}\,P_r/200m\,(=R_n)$ recombinations/sec. This is an oversimplified picture, but it should lead to a suitable approximation.

Now, differentiating Equation (4) with respect to time yields

$$\dot{M} = 2(\dot{N}+\dot{n})m = 4\pi\rho a^2\dot{a} \quad .. \quad (5)$$

If the radius of the sphere decreases at the rate $\dot{a}$, then the number of recombinations/sec., R_n, is

$$R_n = \frac{4\pi\rho a^2\dot{a}\,P_r}{200\,m} \quad .. \quad .. \quad (6)$$

$$= \frac{\rho S\,\dot{a}\,P_r}{200\,m}$$

where $S = 4\pi a^2$, the surface area.

The dissociation energy of molecular nitrogen is about 9·764 eV. or $1{\cdot}564 \times 10^{-18}$ joules, which is also the energy released by each recombination. Some unknown fraction, ζ, of this energy goes into radiated light. One estimate[29] was as high as 50%. The energy radiated as visible light P, is therefore approximately $(R_n\,E_r\,\zeta)$

$$P = \frac{\rho S\,\dot{a}\,P_r\,E_r\,\zeta}{200\,m} \quad .. \quad .. \quad (7)$$

The intensity is given by

$$I = \frac{P}{S} = \frac{\rho\zeta\,\dot{a}\,P_r\,E_r}{200m} \quad .. \quad .. \quad (8)$$

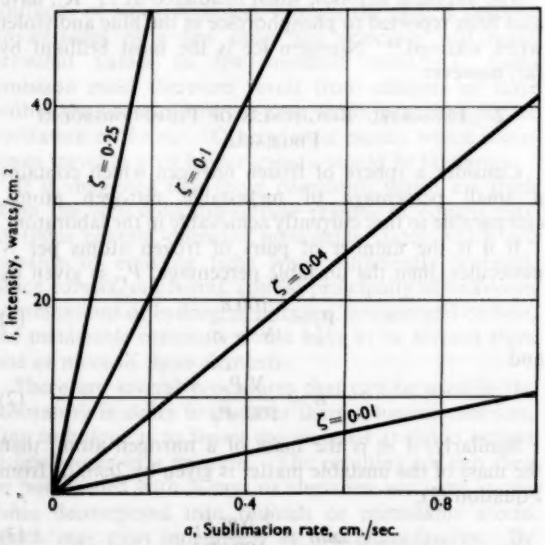


FIG. 2. Estimates of the light intensity at the surface of a subliming sphere which contains a 3% concentration of nitrogen atoms. A sphere sublimating at the rate of 1 cm. per 10 sec. with 10% of the metastable atoms radiating when dropping to ground states has an intensity equal to a tungsten lamp filament at 1700° K. or about 10 W./cm². Most of the light would be centred around 5228·5 Å.

Now assuming that

$$m = 2{\cdot}33 \times 10^{-23}\text{ g.}$$
$$\rho = 1{\cdot}026\text{ g./cm}^3\text{. } (-252{\cdot}5^\circ\text{ C.})$$
$$E_r = 1{\cdot}564 \times 10^{-18}\text{ joules}$$

and

$$P_r = 3 \text{ (see Reference 30),}$$

the intensity becomes

$$I = 1035\,\dot{a}\zeta \quad .. \quad .. \quad .. \quad (9)$$

The intensity I is at the surface of the sphere, and is plotted in Fig. 2 for various ζ. The brightness of a 1700° K. tungsten filament is about equal to 10 W./cm². This is equivalent to a sublimation rate of approximately 0·1 cm./sec. if 10% of the atoms radiate when dropping to ground states and if 3% of the matrix contains metastable nitrogen. The intensity of sunlight is about 0·1 W./cm². on a clear day. If the aforementioned sphere, with an intensity equivalent to a 1700° K. tungsten filament had a radius of 10 ft., it would appear as bright as the Sun at a distance of 105 ft. or as bright as the Moon at a distance of approximately 23,000 ft. Also most of the light would be concentrated in the green, where the eye is sensitive.

VIII. SUMMARY

The basic differences between the unusual fireballs treated here and the common varieties were outlined. A discussion of the different debris responsible for known meteors was also included. It was noted that this material could not be responsible for stationary or very slow meteors.

A chunk of a comet's nucleus, consisting of an ice-dust conglomerate, was then considered as a possible source of bright meteors. The name "cometoid" was introduced to distinguish these objects from meteoroids. Reference was made to a previous paper[2] which showed quantitatively that solid spheres of frozen water could easily absorb the heat influx when entering the atmosphere at speeds of 36,400 ft./sec. Spheres having radii of 1, 5 and 10 ft. were considered. Also, it was observed that many of these objects slowed down to terminal speed (≈500 ft./sec.) while still at altitudes of several miles depending on the angle of entry with the local horizontal.

Cometary ices are believed to be less dense than water and may contain frozen radicals and atoms. However, it was assumed that these objects could also survive re-entry.

The existence of transient cometoid streams was predicted and estimates of the lifetimes of cometoids in space were made.

The large object which impacted in central Siberia in 1908 is believed to have been a rare, retrograde cometoid. The incident is discussed in Appendix B.

The ablation characteristics of inhomogeneous ice mixtures which contain internal energy sources, *e.g.*, molecular fragments, was studied. The following deductions were made:

1. At high altitudes the bodies will sublimate and sharp corners and protrusions will be removed or eroded.

2. Relatively volatile materials will leave the surface regions, making a porous shell of less volatile ice, *e.g.*, water. A process will begin where the more volatile matter slowly leaves the interior. The time required for the highly volatile matter to depart may be comparable to the time of descent, of the order of a few minutes.

3. At lower altitudes the outer shell will be subject to instantaneous melting and refreezing over areas which pass through the forward stagnation region.

4. Gas jets from the interior will help to keep the cometoid turning.

5. Radical recombinations and other sources of heat, such as chemical reactions, will contribute to the fast removal of the remaining internal volatile materials.

6. Internal gas temperatures may reach a few thousand degrees Kelvin. The gas will be in a continuous state of flux. It may be ejected at speeds ot 1 to 3 miles/sec., analogous to the observed ejection velocities of comets. A correction would have to be made in the atmosphere because of the high density of ambient gas.

7. Several different lift forces are discussed for the cometoid model which might keep a slow fireball aloft, or produce a "stationary" meteor for a short time.

8. It was suggested that cometoids may carry their own sources of phosphorescent light. The cold surfaces might glow when the temperatures reached certain critical values corresponding to the point where the frozen metastable species became mobile. The atoms would then radiate a characteristic light by dropping their excess energies. From laboratory experiments it is known that frozen metastable nitrogen can undergo a forbidden transition at 16° K. and radiate strongly in the blue-green. Attempts to measure spectra of slow, green fireballs have not been successful to the author's knowledge (Project Twinkle, U.S.A.F. Cambridge Research Centre) but if the nitrogen afterglow spectrum was observed it could be concluded that the internal temperatures were of the order of 16°–40° K.

The intensity of light emission depends on the rate at which the atoms reach the required temperature. This, in turn, depends on the erosion rate. A cometoid sublimating at the rate of 0·1 cm./sec. could be as bright as a 1700° K. tungsten lamp filament if 10% of the metastable nitrogen atoms radiate when dropping to the ground state.

APPENDIX A

If q is the average convected thermal influx/ft.^{2}/sec., over a sphere which is tumbling at random, then[19]

$$q = 0{\cdot}0145\, M^{3{\cdot}1}\,(p/a)^{\frac{1}{2}} \text{ B.T.U. ft.}^{-2} \text{ sec.}^{-1} \quad .. \quad \text{(A.1)}$$

where

M = Free stream Mach number
p = Ambient pressure, lb. ft.$^{-2}$
a = Radius of sphere, ft.

Equation (A.1) should be valid up to Mach 60 with an error of the order of $\pm 10\%$, and under continuum flow conditions. The conditions of compressibility and dissociation have been included. The equations relating to changes in radii and other characteristics of entry are given in another paper.[3]

APPENDIX B

The Great Siberian Cometoid

Early in the morning (0 hr. 16 min. 7 sec. world time) on 30 June, 1908, an immense object from outer space collided with the Earth. The explosive impact occurred in central Siberia at longitude 102° 0′ E. and latitude 60° 20′ N. in the Podkamennaya Tunguska river basin. The resulting devastation far exceeded that from any other known meteorite in recorded history and it has often been called the most remarkable astronomical event of the twentieth century.

Earthquakes were registered at Irkutsk, Chita and Kabansk in the U.S.S.R. and in microbarograms in England.[31]

Sound phenomena were heard at distances of up to 600 miles. At Kezhma, on the Angar river, a loud noise, similar to thunder, was heard immediately after the fireballs disappeared. The noise lasted for several minutes. This was followed by sounds similar to the firing of large cannon, which shook buildings. These detonations lasted for 2 min.

The large dust cloud associated with this event, which passed over England on 30 June, 1908 and 1 July, 1908, reflected enough light to enable harvesting throughout the night.[32,33]

However, the nature of the damage is indeed singular. No other large meteorite has ever been known to produce a vast mass of hot, high-speed gas. Furthermore, from the complete lack of meteorite fragments of any size, except possibly dust, the object could hardly have consisted of a large iron or stony meteorite of the type found in collections.

The fiery body, which rolled across the sky out of the southwest, fell in a swampy "taiga" (evergreen or coniferous forest) between Yenissei and Lena, about 400 miles north of the trans-Siberian railroad. This particular area, which abounds in swamps, lakes, rivers and mountains, is very difficult to penetrate. Also it was only scantily populated by uneducated Tungus (Mongoloid natives) who lived in the river basins. For these reasons and also because there were no scientists in the general vicinity, scientific researches were not undertaken until 19 years later, in 1927.

At that time Professor Leonid A. Kulik, of the U.S.S.R. Academy of Sciences, made three expeditions to the place of fall. Several attempts were made before the

epicentre was located. If was necessary to penetrate thick underbrush, follow rivers, and improvise rafts.

The general direction of the epicentre actually was not hard to determine. The explosion apparently was radial in its action and the tops of fallen trees were all pointing outwards from the impact area like the spokes of a wheel. They approached the region from the southeast where the first signs of broken trees were seen 37 miles from ground zero. The radial nature of the explosion was evident even at this distance, and it was subsequently verified over the southern and eastern limits. No information was available regarding the northern and western limits.

By the time they came to within 19 to 22 miles of the impact area, there were no longer any trees left standing except in isolated, sheltered places.

In the central area, they found a shallow depression with a radius of about one mile where the ground was compressed and pushed aside. This depressed region contained about 200 shallow craters with steep sides. The majority were filled with mud and some had raised centres, similar to some lunar craters. The diameters ranged from 1 to 50 yards.

The few trees left standing in this region were calcined and stripped of their bark and branches. The entire central area appeared to have been scorched by intensely hot gases. Even after the 19-year interim, a continuous scorching was visible on mosses, bushes and trees as far out as 6 to 10 miles from the centre. This area, which once was a rich forest, was barren and lifeless.

It was estimated that 80 million trees were knocked down or uprooted.

Eye-witness accounts were obtained by Kulik and others from natives who lived along the rivers Angara and Lena, and in the surrounding cities such as Bratsk, Enisseisk, Shamansk and Irkutsk.

The following account, told to Kulik by a native Tungu, gives an indication of the heat intensities involved. Apparently ground zero was used as a pasture for a herd of some 1500 reindeer by one of the wealthier Tungus. A few wooden sheds, which were used for warehouses were also in the area. When the natives returned following the explosions, they found the storehouses ruined, everything having been burned or melted. Only charred carcasses were found and the majority of the herd was never seen again, dead or alive.

Another interesting account is given by Kulik in the words of a native who saw the meteoroid from Vanovara, which is about 18 miles from ground zero:

> "About eight o'clock in the morning, I had been sitting on the porch with my face to the north, and at this moment in the northwest direction appeared a kind of fire which produced such a heat that I could not stand it. This overheated miracle I guess had a size of at least a mile. But the fire did not last long, I had only time to lift up my eyes and it disappeared. Then it became dark, and then followed an explosion which threw me down on the porch about 6 ft. or more. I heard a sound as if all houses would tremble and move away. Many windows were broken, a large strip of ground was torn away and at the warehouse an iron bolt was broken."

Physical Data

The energy of the explosion was expended by several different physical processes. By comparing the observed phenomena at the time of the explosion with known data it is possible to estimate the energies and intensities involved.

Table V is based upon data accumulated by Astopavich and gives estimated values of the explosion energy or intensity.

Table V

Physical quantity	Reference data	Estimated value
Acoustic energy	Cracatoa explosion	10^{21} erg.
Ground shock	Earthquakes	10^{22}–10^{23} erg.
Wind intensity	Hurricanes	10^{20} erg. sec.$^{-1}$
Uprooted Trees	Strength of materials	$4{\cdot}4 \times 10^{21}$ erg.
Light intensity	Sunlight	2×10^{19}–10^{24} erg. sec.$^{-1}$

The initial energy required to realize the above values plus the energy expended in digging out craters and heating the ground might well add up to 10^{22} ergs or more, although Astopavich estimates energies of the order of 10^{20}–10^{21} ergs. If the actual energy is placed between 10^{21} and 10^{22} ergs, then the solid curves in Fig. 3

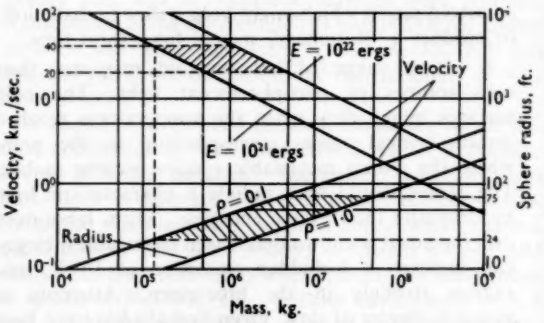


Fig. 3. Relation of the velocity of the Siberian cometoid to the expected mass and size. The energy is assumed to lie between 10^{21} and 10^{22} ergs and the density between 0·1 and 1·0 g./cm.^{3} Russian estimates of speed vary between 20 and 40 km./sec. The corresponding mass is of the order 10^5–10^7 kg. or about 110–11,000 short tons. Depending on the unknown density, the radius of the object must lie between 25 and 100 ft.

relate the mass to the impact velocity, or to an equivalent impact velocity since the entity apparently exploded before impact. This is evident from the numerous craters that were produced.

The trajectory was directed from south to north and had a slope towards the horizon of not more than 18°–24°. The azimuth of the trajectory as seen from the place of fall, was between 164° and 206° N. and the height over the horizon was 4°–24°. This corresponds to a patch on the celestial sphere in the constellation of Cetus. The radiant was not far south of the ecliptic.

It struck the Earth while ascending in its orbit and its motion probably was retrograde.

The object could not have been an ordinary iron or stone meteorite. As pointed out by Kulik, there is no record of any other known meteorite impact which produced such a vast mass of hot gas and which devasted such a large area.

For example, a meteorite, weighing approximately 100 tons, fell in the eastern part of the Soviet Union on 12 February, 1947. The largest of the craters produced was 92 ft. wide and 16 ft. deep. Still, in a photograph of this large crater trees can be seen standing right next to it.[34]

If the object that struck in 1908 was a cometoid, then the actions and damages can be understood. From Fig. 3, the mass of the object must have been in the neighbourhood of 100–10,000 tons. Astopovich estimates 200 tons. An ice-dust entity of this size would have been vaporized and heated to high temperatures upon impact. The instantaneous inferno would pass quickly since the hot gases would blast out to produce a violent but short-lived hurricane. Iron and stone meteorites do not tend to produce hurricane-like effects since the vapours condense out quickly, and most of the mass would not have vaporized.

The gases produced by a cometoid upon impact would consist largely of carbon dioxide, water, methane and ammonia in addition to deadly poisons such as hydrogen cyanide and cyanogen. The latter gases would quickly rise and clear the area, however.

ACKNOWLEDGEMENTS

The author would like to thank Mr. H. Q. Driscoll for reading the paper, and would like to acknowledge that this paper was sponsored by the Convair Writing Award Fund.

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CORRESPONDENCE

Orbit of the Moon

SIR,

In the interesting paper of Dr. Slater,[1] I read on p. 323: "... the Moon, the plane of whose orbit is inclined 5° to that of the ecliptic, and rotates round the latter once every 18 years 10 days."

This is not correct, the exact value being 18·6 years ("nutation" of the Moon's orbit); 18 years 10 days is the length of one Saros, a period after which the eclipses of Sun and Moon repeat themselves with great exactness.

The last maximum of the inclination of the Moon's orbit to the equator of the Earth occurred in August, 1950; the inclination was then 23° + 5° = 28°, and the Moon's ascending node coincided with the vernal point. 9·3 years later, after a half-period of the nodes, the inclination was minimum (23° − 5° = 18°); this occurred in December, 1958.

The next maxima of the inclination will be in March, 1969; November, 1987; June, 2006; etc. The next minima will be in: July, 1978; March, 1997; etc.

I beg to remain, Dear Sir,
Very truly Yours,
JEAN MEEUS.
Eigenaar.

Kesselberg Sterrenwacht,
Bergstraat, 65,
Kessel-Lo, Belgium.
30 *June*, 1960.

REFERENCE

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REPORT OF COUNCIL

FOR THE YEAR ENDED 31 DECEMBER, 1959

CHAIRMAN'S ADDRESS

I intend to keep my address as brief as possible and confine myself to the positive activities of the Society during the past year. Brevity does not, however, indicate a lack of action, for I would venture to state that during the past year our activities have exceeded in scale and scope anything that we have done previously.

International Meetings

The main items in our programme, of course, were the Tenth International Astronautical Congress and the Commonwealth Spaceflight Symposium which ran concurrently from 27 August to 5 September, 1959. The Commonwealth Spaceflight Symposium was an experimental venture in which our aim was to discuss the possible part which the U.K. and Commonwealth countries might play in spaceflight. We were very pleased that the Australian High Commissioner honoured us by opening this meeting and that we were able to welcome many representatives from Commonwealth countries who participated in the discussions. I think that we can fairly regard the Commonwealth Symposium as having been a success. Papers were presented by Australian, Canadian and Indian visitors and by delegates from industry and universities in the U.K. and the two and a half days occupied by the meeting were taken up by lively discussions both inside and outside the lecture halls.

The occasion of the International Astronautical Congress was a very special one, for this was the tenth meeting and the second to have been held in Westminster. In 1951 we held the Second International Astronautical Congress at Caxton Hall. The Tenth Congress, which appropriately enough exceeded the second in attendance by a factor of five, had to be held in the much larger Church House—about a quarter of a mile away from the previous venue.

It was a great honour for the Society to have had a second opportunity of welcoming to London our friends from the astronautical societies of other countries. However, we approached our task with some trepidation, for we knew from the rate of expansion of successive Congresses that we could expect an extremely large gathering at London. In the event, over six hundred participants registered at the Congress and we were faced with some particularly difficult problems of organization. It seems to have been the general opinion of those present that, apart from one or two minor slips, we overcame the problems most successfully. I must record here that this would not have been possible had it not been for voluntary and professional services which we were able to obtain at no expense to the Society. The volunteers consisted of more than thirty of our members who gave up almost a fortnight's holiday to join the Secretary and other Officers of the Society in the preparation and day-to-day running of the Congress and Symposium. The professional help came from members of the Staff of the Hawker Siddeley Group who were "seconded" to the Society to help with the organization both before and during the Congress. I want to express here the sincere thanks of the Council to all those people who made this valuable effort.

I will not take up your time by giving details of the Congress itself, but I would like to record the fact that this marked the first time that any activity of the Society has received formal support from the Government. On this occasion we were privileged to have the proceedings opened by the Minister of Supply, Mr. Aubrey Jones, who later entertained all the participants, at a reception at Lancaster House. This reception was greatly appreciated by our overseas visitors in particular. To the Society, this official action was welcome in that it appeared to indicate that the Government was showing a positive interest in astronautics.

I would like to turn now to what I consider to have been the most important work undertaken by the Society. In the past we have interpreted the role of the B.I.S. as being that of a learned society disseminating scientific and technical information and stimulating research and development in the field of astronautics. At the same time we have considered it to be our duty, equally, to inform a much wider public about the problems and possibilities of spaceflight. These tasks we have pursued to the best of our ability over the years during which the Society has been in existence. This year, however, the Council decided that we should take a more definite stand on the need for the U.K. to embark upon a programme of development in astronautics. We felt that the official bodies advising the Government were concerned only with so-called space research and that the wider technological significance and commercial possibilities of satellites and space vehicles were not being taken into account.

Recommendations to H.M. Government

It is not necessary for me to go into many details of the steps we have taken to put before the Government the Society's views on these matters, since you will have seen these set out in recent issues of the *Journal* and ***Spaceflight*** and although these activities were initiated by the Technical Policy Committee during the period under review, they have mainly taken place during the last few months. However, I think it is appropriate to record some of the salient points.

Towards the end of 1959, we set up a special panel which met for the first time on 15 January, 1960. The members of the panel were drawn mainly from people who had taken an active part in the Commonwealth Spaceflight Symposium. The panel considered the extent to which the U.K. could participate in the development of spaceflight, with the emphasis on technological aspects rather than on space research. As an outcome of the first two meetings a memorandum, which you have seen, was drawn up and submitted to the Prime Minister. Subsequently, a delegation from the Society was invited to attend a meeting with the Minister of Science and his advisers. This meeting took place shortly after the cancellation of Blue Streak as a military project and one of the main concerns of the Government was to obtain a picture of the technological and possible commercial benefits which might be derived from the continued development of this vehicle for astronautical purposes. As an outcome of the meeting with Lord Hailsham, the Society's representatives drew up a Second document outlining the possible impact of spaceflight development on technology in general and the immediate practical importance of these developments. This document which we have subsequently published, has received very careful consideration by official departments.

Finally, in this connection, representatives of the Society met an all-party group of M.P.s at the House of Commons and to them presented our views on the significance of astronautical research and development to an industrial nation such as the U.K. As you will have read in the press, an outcome of this meeting was a decision of the Members present to set up a Parliamentary Committee on Space.

It is too early to discover whether our efforts will have influenced the Government in its decision regarding the participation of the U.K. in this vital field. However, we have made every possible effort to influence them in a positive direction and we will continue to do our utmost in the future, to follow up our actions. I would like to stress, at this point, that while it is the view of the Council that the U.K. on its own can play a useful part in the exploration of space, it is only by a joint programme with European and Commonwealth countries that we can hope to set up a "third force" in space that would be able to compete on equal terms with the United States and the Soviet Union. We believe that the existence of such a third force may be an essential step towards full international collaboration in this field. In our future activities, therefore, we are likely to place great emphasis on the desirability of joint efforts.

Society Meetings and Publications

Turning next to the more usual activities of the Society, I am able to report that we have continued to hold our normal level of lecture programmes, in London and in the provinces. In the London area we were privileged to welcome Professor Alla Masevich from the U.S.S.R., who addressed a meeting of the Society at Church House. This lecture was particularly well attended, about 600 people being present.

We have been encountering certain difficulties in meeting publication schedules with the *Journal* and ***Spaceflight*** consequent upon the dispute in the printing industry. The hard-pressed and over worked editors are now confident that they are over the difficult period and everything humanly possible will be done in future to maintain the correct time table. We can only point out with regard to the past year that, while the dates have gone somewhat astray, we have, nevertheless, maintained the full volume of published material and we hope that we have kept the high standard that it is our objective to maintain.

Financial Status and Membership

The financial state of the Society has not improved to an extent which the Council and Officers would have liked. However, as you can see from the published annual accounts, we were able to show a profit on the year's transactions despite a substantial deficit on the Congress. The need for expanding our revenue is as great as ever and we must spare no effort to do so. Membership subscriptions do not appear to be the means whereby this expansion can be achieved, for, despite the efforts of our much stronger Membership Committee, the rate of increase of membership over the past year has been small. I am of the opinion that we cannot expect really large increases in the number of members until Britain has a real space programme in being, to provide a reservoir of professional people with a direct interest in astronautics.

Washington Informal Group

In mentioning our membership, I think it is appropriate to draw your attention to the Metropolitan Washington Branch of the Society which was established about a year ago and is now flourishing in a remarkable manner. I would like to take this opportunity of conveying to the Officers of this first overseas branch of the Society, the Council's good wishes for the success of their endeavours. We hope that this group will help to cement our very friendly relations with the American Rocket Society and American Astronautical Society.

Council, Committees and Officers

I want to speak finally about the Council and Officials of the Society. As you will recall, in my previous addresses I drew your attention to the need for setting up the administration of the Society on a proper professional basis. In pursuance of this policy, the Council has now appointed Mr. L. J. Carter as full-time salaried Secretary. Those among you who are aware of the work carried out by the Secretary will ask, perhaps, how he could possibly work more "full-time" than before. I can only answer you by saying that now, at least, the matter has been placed on a proper footing, in so far as Mr. Carter now works officially for the Society. I am sure you will all join me in wishing him every success in his appointment.

Finally, as you know, the Council was enlarged by three members last year in order to cope with the increased volume of Society's business. Despite this increase, demands on individual members of the Council have increased owing to the many active committees which we now run. I must thank my fellow councillors for the hard work they have put in during the year. Particular thanks are due, as always, to our two editors, Mr. K. W. Gatland and Mr. G. V. E. Thompson, for their continued efforts in bringing out our publications.

I must record the departure from the Council of Mr. D. J. Cashmore, who has rendered great services to the Society and who merits our sincere thanks for these services. I hope that while we may not see him again on the Council, at least for the present, we may nevertheless enjoy the benefits of his advice and participation in our future activities. To conclude I must remind you of the fact that this is my last appearance as Chairman of the Society. I wish my successor the best of luck in this office and I would like to assure him that he can count on my cooperation and assistance at all times.

L. R. SHEPHERD
Chairman of Council

MEMBERSHIP

The number of members in the various grades at 31 December, 1958 and 1959, were as follows:

	1958	1959
Honorary Fellows	5	5
Fellows	1007	1194
Associate Fellows	—	35
Senior Members	99	162
Members	2148	1907
	3259	3303
Corporate Members	—	2

COUNCIL AND OFFICERS

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A. H. S. CANDLIN, B.Sc.(Tech. Chem.), Assoc. I. Mech.E.

D. J. CASHMORE, M.Sc.

M. N. GOLOVINE, M.B.E., A.C.G.I., A.F.R.Ae.S.

S. W. GREENWOOD, B.Sc., M.Eng., A.M.I.Mech.E., A.F.R.Ae.S.

D. HURDEN, B.A., G.I.Mech.E.

N. H. LANGTON, M.Sc., Ph.D., A.M.Brit.I.R.E., A.Inst.P.

N. R. NICOLL

A. E. SLATER, M.A., M.R.C.S., L.R.C.P., F.R.Met.S.

E. T. B. SMITH, B.Sc., D.C.Ae., A.M.I.Mech.E., A.F.R.Ae.S.

G. V. E. THOMPSON, B.Sc., B.Sc.(Eng.), A.R.C.S., F.R.I.C., A.I.L., L.I.M.

Secretary

L. J. CARTER, A.C.I.S.

COMMITTEES

The main committees of the Society which have served during the year were constituted as follows at 31 December, 1959:

FINANCE AND GENERAL PURPOSES COMMITTEE

*SHEPHERD, Dr. L. R. (*Chairman*)
*CARTER, Mr. L. J.
GATLAND, Mr. K. W.
*THOMPSON, Mr. G. V. E.

* Benevolent Fund Trustees

HONOURS AND AWARDS COMMITTEE

SHEPHERD, Dr. L. R. (*Chairman*)
ALLEN, Mr. J. E.
BRENNAN, Mr. M.

I.A.F. COMMITTEE

SHEPHERD, Dr. L. R. (*Chairman*)
CANDLIN, Mr. A. H. S.
CARTER, Mr. L. J.
THOMPSON, Mr. G. V. E.

MEMBERSHIP COMMITTEE

BRENNAN, Mr. M. (*Chairman*)
ALLEN, Mr. J. E.
CANDLIN, Mr. A. H. S.
HURDEN, Mr. D.
MAXWELL, Dr. W. R.

PROGRAMME COMMITTEE

MAXWELL, Dr. W. R. (*Chairman*)
CASHMORE, Mr. D. J.
HURDEN, Mr. D.
LANGTON, Dr. N. H.
NICOLL, Mr. N. R.

PUBLICATIONS COMMITTEE

THOMPSON, Mr. G. V. E. (*Editor* and *Chairman*)
CASHMORE, Mr. D. J.
LANGTON, Dr. N. H.
SLATER, Dr. A. E.

SPACEFLIGHT EDITORIAL BOARD

GATLAND, Mr. K. W. (*Editor* and *Chairman*)
ALLWARD, Mr. M. F.
CROSS, Mr. C. A.
HURDEN, Mr. D.
SLATER, Dr. A. E.

TECHNICAL POLICY COMMITTEE

SHEPHERD, Dr. L. R. (*Chairman*)
BRENNAN, Mr. M.
CASHMORE, Mr. D. J.
GREENWOOD, Mr. S. W.
LANGTON, Dr. N. H.
THOMPSON, Mr. G. V. E.

B.I.S./INSTITUTE OF NAVIGATION JOINT SYMPOSIUM COMMITTEE

*ANDERSON, W/Cdr. E. W. (*Chairman*)
*CASHMORE, Mr. D. J.
†FRASER, Mr. D. O.
*GREENWOOD, Mr. S. W.
*LANGTON, Dr. N. H.
†MAJENDIE, Capt. A. M. A.
†RICHEY, Mr. M. W.
*THOMPSON, Mr. G. V. E.

* Representing the B.I.S. † Representing the Institute of Navigation.

B.I.S./SOCIETY OF INSTRUMENT TECHNOLOGY JOINT SYMPOSIUM COMMITTEE

*MEDLOCK, Mr. R. S. (*Chairman*)
†CARTON, Mr. D. S.
†LANGTON, Dr. N. H.
†MAXWELL, Dr. W. R.
*PARTON, Prof. J. E.
*POLLARD, Cmdr. A. A. W.
*REAM, Mr. N.
*SNARE, Mr. E. F.
†WYKE, Mr. F. R.

* Representing the S.I.T. †Representing the B.I.S.

EUROPEAN SPACEFLIGHT SYMPOSIUM COMMITTEE

SHEPHERD, Dr. L. R. (*Chairman*)
CANDLIN, Mr. A. H. S.
CARTER, Mr. L. J.
GOLOVINE, Mr. M. N.
THOMPSON, Mr. G. V. E.

FIFTEENTH ANNUAL GENERAL MEETING

The Fifteenth Annual General Meeting of the British Interplanetary Society was held in the Lancaster Room, Caxton Hall, Caxton Street, London, S.W.1 on Friday, 15 July, 1960.

Present:

Dr. L. R. Shepherd (*President*) in the Chair
K. W. Gatland (*Vice-President*)
L. J. Carter (*Secretary*)
and about twenty-one other members of the Society.

The Secretary read the notice convening the meeting which had been printed in the June issue of the *Journal*. He mentioned that Council had recently decided that the offices of President and Vice-President should be substituted for those of Chairman and Vice-Chairman respectively, so that Dr. Shepherd was now making his first appearance as President at a public meeting of the Society.

Chairman's Address

Dr. L. R. SHEPHERD said that this fifteenth annual general meeting was the sixth he had had to address directly or indirectly. It had not proved possible to circulate his address to members prior to the meeting but it would appear in a future issue of the *Journal* (see p. 412 of this issue). He therefore summarized its contents, concluding by reminding members that this would be his last appearence as Chairman or President of the Society and wishing his successor the best of luck in this office.

Annual Statement of Accounts and Balance Sheet

The SECRETARY presented the accounts and balance sheet for the year ended 31 December, 1959, (see pp. 332-333 of the June issue of the *Journal*), and stated that, although these were most satisfactory, there was underlying cause for anxiety because the Society's finances did not match up to our future requirements and left little room for expansion. It was vital that we should endeavour to increase our income in every possible way, and although advertising seemed to be a suitable field for achieving this, it proved most difficult to accomplish in practice. Our advertising agents, Cheiron Press Ltd., had done much to circulate manufacturers and industrialists who might be interested and this was a matter which we intended to pursue even more energetically. Our advertising in the past was due in no small measure to the help and goodwill which we had received from members in influential positions who had supported our endeavours.

It was particularly gratifying that the number of libraries receiving our publications had shown a further growth during the year, as this was of very real benefit to the Society. It was also a way in which members could actively assist the Society's growth by discussing the matter with the Librarian or Information Officer of their Company or Establishment and suggesting that the firm subscribes. We are always pleased to send specimen copies of publications for this purpose.

Mr. E. HOPE-JONES (Fellow) asked if it was a printer's error that the Congress Financial Summary (p. 332) showed the Amount paid by the Society as £951, whereas the expenditure account (p. 333) gave Contribution and Expenses of Congress as £1104.

The SECRETARY explained that the £951 was contained within the £1104, which also included the Society's contribution to the International Astronautical Federation.

Mr. E. HOPE-JONES then proposed that the Balance Sheet and Accounts for the period to 31 December, 1959, be approved. This was seconded by Mr. F. R. FEARS (Fellow), and on being put to the meeting was carried *nem. con.*

Election of Members of Council: Report of Scrutineers

The President said that six nominations had been received for the five vacancies on the Council, and were as follows:

DENNIS HURDEN, B.A., G.I.Mech.E. (Fellow).
Age 36. Assistant Chief Engineer, Rocket Division, de Havilland Engine Co. Ltd.

WILLIAM FRANK HILTON, Ph.D., D.Sc., A.R.C.S., D.I.C., F.R.Ae.S. (Fellow).
Age 48. Head of Astronautics Division, Advanced Projects Group, Hawker Siddeley Aviation Ltd.

GEOFFREY KEITH CHARLES PARDOE, B.Sc.(Eng.), D.L.C., A.F.R.Ae.S. (Fellow).
Age 31. Manager, Blue Streak Project Office, de Havilland Propellers Ltd.

LESLIE ROBERT SHEPHERD, B.Sc., Ph.D. (Fellow).
Age 41. Head of Research and Development OEEC "Dragon" Project. United Kingdom Atomic Energy Authority.

EVERS TURNER BUCHANAN SMITH, B.Sc., D.C.Ae., A.M.I.Mech.E., A.F.R.Ae.S. (Fellow).
Age 39. British Joint Services Mission, Washington, D.C.

GORDON VALLINS ELLIOT THOMPSON, B.Sc., B.Sc.(Eng.), A.R.C.S., F.R.I.C., A.I.L., L.I.M. (Fellow).
Age 39. Senior Information Officer, The British Non-Ferrous Metals Research Association.

Dr. SHEPHERD then called upon Mr. E. Hope-Jones to give the Report of the Scrutineers on the Postal Ballot for the election of the five Members of Council.

Mr. HOPE-JONES stated that a total of 589 ballot papers had been received, of which four were invalid. He stated that the following five nominees had received most votes:

1. Dr. L. R. Shepherd, 2. Mr. D. Hurden, 3. Dr. W. F. Hilton, 4. Mr. G. V. E. Thompson, 5. Mr. G. K. C. Pardoe.

Mr. HOPE-JONES proposed that these members should be elected and this was seconded by the other scrutineer, Mr. G. W. SAVAGE (Member), and carried unanimously.

Dr. SHEPHERD said that it was very gratifying to welcome Dr. Hilton and Mr. Pardoe as new members of the Council. He then asked the meeting to approve a vote of thanks to Mr. E. T. B. Smith, the unsuccessful candidate, who had carried out Trojan work for the Society over many years in the past and who would undoubtedly continue to do so, even though distance prevented him from attending meetings in this country. This proposal was carried by acclamation.

Report of the Benevolent Fund Trustees

Mr. L. J. CARTER then gave the Report of the Trustees of the Benevolent Fund. He began by saying that the Trust Deed which had been drawn up to govern the operation of the Fund would be published in the *Journal* shortly so that all members would be fully informed of this (see p. 416).

During the past year the receipts from members had been very poor and at the present time the assets totalled £910, of which three-quarters had been provided by the Society itself from its general funds. The Trustees felt that a minimum capital of £3000 was essential, the income from this being sufficient to make one or two modest grants during the course of each year. It was extremely important that this minimum capital sum be achieved without delay and his impression was that the members as a whole did not feel that they were directly concerned. It was essential to realise that the Benevolent Fund was a worthwhile objective of the Society which deserved adequate support. It was most distressing for the Council to learn of the occasional misfortune including death or serious accident to some of our members, many of whom had supported this Society over many years both financially and in other ways. In the past members have been killed or hurt in car and air crashes, one at least in a mountaineering accident, and although not all of these would necessarily have led to a claim on the Benevolent Fund, there was a clear indication that a small grant to tide over the immediate shock could achieve a most humane purpose. During the year the Trustees had prepared a Deed of Covenant which was now available to any member who wished to make regular donations, however modest, to the Benevolent Fund. The affect of this Covenant is that members undertake to remit a certain stated amount each year for a minimum period of 7 years and, in so doing, enable the Trustees to claim a refund of income tax paid. This involves no additional obligation on the member concerned but is a very useful means of augmenting the Fund's capital.

Another matter which had been suggested was the question of whether any members would like to make some provisions for the Fund in drafting their Will. To assist them, a clause had been drawn up for inclusion in such Wills and is as follows:

> "I give . . . (Free of Duty) to the Trustees of the Benevolent Fund of the British Interplanetary Society Limited and I direct that the receipt of the Treasurer or other proper officer for the time being thereof shall be an effectual discharge to my Trustees in respect of the said . . ."
> (*the sum of money or other gift is to be specified in both blank spaces*).

Group Captain WICKS said that the Trustees should not be diffident in asking for money. All members are always being asked for cash for various reasons and from a wide variety of sources. It was entirely a case of the one who shouts the loudest getting the cash!

Mr. HOPE-JONES asked if there would be any financial gain for the Society to effect insurance for members on the lines undertaken by similar organisations.

The SECRETARY replied that he was not keen to undertake the additional obligation of effecting insurance requirements for members though there was a point that if members did not contribute to the Benevolent Fund, they might need insurance more than formerly.

It was then proposed by Mr. G. V. E. THOMPSON (Fellow) that the Benevolent Fund Account and Report be accepted and, after seconding by Mr. G. W. SAVAGE (Member) this was carried unanimously.

General Discussion of the Affairs of the Society

The PRESIDENT said that he hoped that members would now raise any points concerning the Society.

Mr. R. G. CRUDDACE (Fellow) said that an increased membership could not be expected until a British Space Programme was started. He supported the idea of a vigorous campaign to attract new members in the Establishments, Ministries and firms.

Mr. G. V. E. THOMPSON (Fellow) asked if anything was being done about the venue of meetings.

Dr. SHEPHERD replied that we required better-equipped lecture halls and the view of the Council is that we should look around now for suitable places. During the next few years we should not fix ourselves very firmly to any particular venue and would be somewhat nomadic. We have already stopped holding Council meetings at Caxton Hall—these are all now held in the Council Room of the Royal Commonwealth Society. In the future we aspire to possessing our own lecture hall and will certainly need financial support from our members and many other sources to achieve this.

Dr. S. C. GHOSE (Fellow) suggested that the Society should issue posters asking members to join, phased particularly for appeal to the electronic, aeronautical, and other industries.

The SECRETARY replied that we already prepared large display posters for lectures and these provided an indirect means of advertising. The main point was that it is much better to send a lecture poster to a particular member who would undertake to get it displayed rather than send out large numbers of such posters willy-nilly, knowing that most of them would be thrown away. A number of members then indicated that they could arrange for lecture posters and other leaflets to be displayed and the Secretary replied that he was very grateful for this support. He said that an appeal would be made in a future issue of the *Journal* for any other members similarly placed to notify him that they could assist in this way in order that he could send them material.

A member suggested that there should be space on the posters for insertion of a local representative's name, and this idea was supported by Mr. M. BRENNAN and others.

Several members also said that they would endeavour to persuade their Libraries to take the Society's publication.

In regard to meetings, the SECRETARY stated that we now needed to draw more freely on the services of our members to act as Stewards and organisers for meetings. Any members who would like to take part in this type of activity were invited to write to the Secretary.

There being no other business, the Annual General Meeting was ended.

THE BRITISH INTERPLANETARY SOCIETY BENEVOLENT FUND

TRUST DEED

This TRUST DEED is made the Fifth day of August One thousand nine hundred and sixty BETWEEN the persons specified in the Schedule hereto (hereinafter called "the Donors") of the one part and LEONARD JAMES CARTER of 1 Woodmansterne Road Carshalton Beeches in the County of Surrey LESLIE ROBERT SHEPHERD of Thuban Charborough Road Broadstone Poole in the County of Dorset and KENNETH WILLIAM GATLAND of 42 Knightwood Crescent New Malden in the County of Surrey (hereinafter called "the Trustees" which expression shall include the trustees or trustee from time to time hereof) of the other part:

WHEREAS each of the Donors has paid to the Trustees the sum of One pound and it is apprehended that other persons or companies may hereafter pay or transfer to the Trustees cash or property to be held upon the charitable trusts and with and subject to the powers and provisions herein declared:

NOW THIS DEED WITNESSETH as follows:

1. THE Trustees shall stand possessed of any property hereafter transferred to them to be held upon the trusts hereof upon trust that the Trustees may either allow the same or any part thereof to remain as actually invested or laid out so long as the Trustees in their absolute discretion may think fit or may at any time or times sell call in or convert into money the same or any part thereof and shall invest or lay out the net proceeds of sale and the sums paid by each of the Donors as aforesaid and any other sums which may hereafter be paid to the Trustees to be held upon the trusts hereof and any other capital moneys which may be received by the Trustees in the names or under the legal control of the Trustees in or upon any investments or property hereby authorised with power at their discretion to vary or transpose any investments or property for or into others of any nature hereby authorised.
2. THE TRUSTEES shall stand possessed of the sums paid by each of the Donors as aforesaid and any property or cash hereafter transferred or paid to the Trustees to be held upon the trusts hereof and the investments and property from time to time representing the same (hereinafter called "the Trust Fund") upon such charitable trusts and for such charitable purposes as the British Interplanetary Society Limited or the Council for the time being thereof shall from time to time in writing appoint.
3. SUBJECT to and in default of and until any such appointment as aforesaid the Trustees shall apply the income of the Trust Fund in or towards the relief of poverty by the distribution of gifts of money necessary provisions and comforts to and among such poor and needy members from time to time or poor and needy former members of the British Interplanetary Society Limited and such poor and needy wives husbands widows widowers children and remoter issue of members or former members of the British Interplanetary Society Limited or some or one of them in such amount and quantity and in such manner as the Trustees shall in their absolute discretion from time to time determine.
4. THE TRUSTEES shall have the following powers exercisable from time to time as they may think proper namely:
   (*a*) To pay all or any part of the expenses necessarily incurred in the administration of the Trust Fund or the application of the net annual income thereof.
   (*b*) To accumulate income.
   (*c*) To make and vary rules with respect to and otherwise determine the eligibility of beneficiaries of the charity hereby constituted but so that preference shall as far as possible be given to poor members or poor former members who have been members of the British Interplanetary Society Limited for upward of five years and their respective poor wives husbands widows widowers children and remoter issue.
   (*d*) To do all such lawful acts and things as are necessary or expedient for the proper administration or incidental to the attainment of the objects of the said charity.
   (*e*) To invest or lay out trust moneys in the purchase of or at interest upon the security of such stocks funds shares securities or other investments of whatsoever nature and wheresoever and whether involving liability or not as the Trustees shall in their absolute discretion and without being liable for any loss from time to time think fit.
5. NOTWITHSTANDING the trusts and powers hereinbefore contained the Trustees may at any time or times with the consent in writing of the British Interplanetary Society Limited, or if it shall cease to exist at the absolute discretion of the Trustees apply the whole or any part of the capital or income of the Trust Fund to or for such charitable purposes whether or not connected with the British Interplanetary Society Limited as the Trustees shall in their absolute discretion determine.
6. (1) THE Trustees shall meet and otherwise regulate their meetings as they may think fit and two of them shall form a quorum.

   (2) Any power of discretion vested in the Trustees shall be deemed to be properly exercised if such exercise be approved or authorized by a majority of the Trustees present at any meeting at which a quorum is present.

   (3) The Trustees shall keep or cause to be kept full and proper accounts of the application of the capital and income of the Trust Fund.
7. The power of appointing new and additional Trustees shall be vested in the British Interplanetary Society Limited and shall for all purposes be deemed to be duly exercised by any Deed of Appointment purporting to be executed by not less than two members of the Council for the time being of the British Interplanetary Society Limited.

IN WITNESS whereof the parties hereto have hereunto set their hands and seals the day and year first before written.

THE SCHEDULE hereinbefore referred to

Norman Robson Nicoll 93 Leighswood Avenue Aldridge in the County of Stafford Gordon Vallins Elliot Thompson 1 Herbert Road Hornchurch in the County of Essex Michael Golovine 205 Grove End Gardens London N.W.8 Norman Harry Langton 37 Cheyne Avenue Woodford in the County of Essex William Ralph Maxwell 100 Ellesborough Gardens Wendover in the County of Buckingham and Dennis Hurden The Market House Sawbridgeworth in the County of Hertford.

NEWS AND ANNOUNCEMENTS

B.I.S. NEWS

Council and Officers, 1960

At the Annual General Meeting held on 15 July (reported in detail on p. 414–415), D. Hurden, Dr. L. R. Shepherd and G. V. E. Thompson were re-elected Members of Council; Dr. W. F. Hilton and G. K. C. Pardoe were elected to fill the remaining vacancies.

At a meeting of the new Council held on 24 September, Dr. W. R. Maxwell was elected President of the Society, and took office as from that date. M. Brennan and K. W. Gatland were elected Vice-Presidents. On behalf of the Society, Dr. Maxwell tendered to the outgoing President (Dr. L. R. Shepherd) thanks for all the work he has done in the service of the Society and astronautics.

Branch Secretaries

Mr. J. O. Leonard, B.S. (13902 Parkland Drive, Rockville, Md., U.S.A.) has replaced Mr. Freeman G. Lee as Secretary of the Metropolitan Washington Branch of the Society. The address of Mr. W. Devine, Secretary of the South Shields Informal Group, is now 146 Highfield Road, South Shields.

JOINT ACTIVITIES

Symposium on Rocket Propulsion

As previously announced, a two-day symposium on rocket propulsion is being organized jointly by the British Interplanetary Society, the College of Aeronautics and the Royal Aeronautical Society. It deals with both liquid- and solid-propellent rockets, and particular emphasis is being placed on British work.

The symposium is to take place at the College of Aeronautics, Cranfield from 12 Noon on Friday 6 January, 1961, to 6 p.m. on Saturday, 7 January, 1961. The Conference Fee (covering the provision of preprints, entrance to the meetings and accommodation and meals at the College) is £6. Applications should be sent to the Royal Aeronautical Society, 4 Hamilton Place, London, W.1.

The provisional programme is as follows:

Friday, 6 January

12.00 *Luncheon.*

1.15 p.m. *Introduction and Welcome*, by Professor A. J. Murphy (Principal, College of Aeronautics).

1.30–2.30 p.m. *Control of Solid Motors.*

"Thrust Axis Control in Solid Propellent Rocket Motors," by J. M. Carter (Summerfield Research Station, Imperial Chemical Industries, Ltd.).

"Solid Propellent Dual Thrust Motors," by H. M. Darwell (Summerfield Research Station, Imperial Chemical Industries, Ltd.).

2.30–4 p.m. *Control of Liquid Engines.*

"Starting and Stopping a Rocket Engine," by A. W. T. Mottram (Bristol Siddeley Engines Ltd.).

"Thrust Throttling of Large Liquid Propellent Rocket Engines," by I. E. Smith (Rolls-Royce, Ltd.).

4.00 p.m. *Tea.*

4.30–6 p.m. *Control of Liquid Engines and Systems.*

"Throttling—the de Havilland Spectre," by R. V. Watts (de Havilland Engine Co. Ltd.).

"Black Knight—Directional Control," by H. G. R. Robinson (Ministry of Aviation, Royal Aircraft Establishment, Farnborough).

Saturday, 7 January

9.30–10.15 a.m. *Liquids Instruments and Measurement*

"Instrumentation Techniques in Rocket Testing," by W. R. Beakley (Ministry of Aviation, Rocket Propulsion Establishment, Westcott).

"Measuring Pump Efficiency," K. Christie (de Havilland Engine Co. Ltd.).

10.15–11.00 a.m. *Solid Motor Measurements.*

"Measurement of Specific Impulse and Burning Rate," by G. W. Stocks (Ministry of Aviation, Explosives Research and Development Establishment, Waltham Abbey).

"Internal Ballistic Problems in Solid Propellent Rocket Motor Charges," by R. Heron (Ministry of Aviation, Rocket Propulsion Establishment, Westcott).

11.00 *Coffee.*

11.30–12.15 p.m. *Liquid Propellents.*

"Packaged Liquid Propellent Rocket Engines," by K. G. Page (Rocket Division, de Havilland Engine Co. Ltd.).

"The Role of Liquid Hydrogen as a Propellent," by G. T. Healey (Bristol Siddeley Engines Ltd.).

12.30 p.m. *Luncheon.*

2–3 p.m. *Solid Motor Reliability.*

"Metallurgical Aspects in the Production of High Strength Rocket Motor Cases," by P. F. Langstone (Bristol-Aerojet Ltd.).

"Inspection Problems in Solid Propellent Rocket Motor Charges," by C. G. Lawson (Ministry of Aviation, Explosives Research and Development Establishment, Waltham Abbey).

3 p.m. *Tea.*

3.30–5.45 p.m. *Rocket Engine Reliability.*

"Reliability of Rocket Engines," S. L. Bragg (Chief Scientist, Rolls-Royce, Ltd.).

"Design for Reliability of Liquid Propellent Rocket Engines," by E. G. D. Andrews (Chief Designer, Rockets Division, Bristol Siddeley Engines, Ltd.).

"Development for Reliability of Liquid Propellent Rocket Engines," by A. W. Broomfield (Bristol Siddeley Engines Ltd.).

Contributions to the discussion will be welcomed.

Members and others wishing to attend the Symposium are asked to notify the Secretary, British Interplanetary Society, 12 Bessborough Gardens, London, S.W.1, from whom further particulars and application forms may be obtained.

ASTRONAUTICAL ABSTRACTS

Edited by J. HUMPHRIES and J. FOLEY

1959–60 PARTS 10/11

A list of abbreviations of titles of journals was included with the 1954 index and addenda have been published in subsequent issues of the *Journal*. A further addendum is given below:

Appl. Hydr. Pneum.	Applied Hydraulics and Pneumatics.
Engng. News.	Engineering News.
Engng. News Record.	Engineering News Record.
Geophys. J.	Geophysical Journal.
Industr. Qual. Control.	Industrial Quality Control.
Proc. Phys. Soc.	Proceedings of the Physical Society
Proc. Roy. Soc. [A].	Proceedings of the Royal Society. [Part A].
Pub. Math. Inst. Hung. Acad. Sci.	Publications of the Mathematical Institute of the Hungarian Academy of Science.
Rev. Inst. franç. Pétrole.	Revue de l'Institut français du Pétrole et Annales des Combustibles liquides.
Rev. Méc. Appl.	Revue de Mécanique Appliquée.
Riv. Combust.	Rivista dei Combustibili.
Stud. Cerc. Mec. Apl.	Studii şi Cercetari de Mecanică Aplicată.
U.S. Armed Forces Med. J.	U.S. Armed Forces Medical Journal.
Welding Engr.	Welding Engineer.
Z. Flugwissenschaften.	Zeitschrift für Flugwissenschaften.

1—ASTRONOMY

.1 *General*

(2173) **"Geography" of space: spatiography.** H. Strughold. *Weltraumfahrt*, **9**, 65–8 (*Sept.*, 1958). (*In German.*) [For English version, see *Missiles and Rockets*, **3**(6), 106, 108 (*May*, 1958)].

(2174) **Dictionary of astronomy and astronautics.** A. Spitz and F. Gaynor. 439 pp., *Philosophical Library, N.Y.* (1959).

(2175) **Recent developments in the study of interstellar and interplanetary media.** V. G. Fesenkov. *Priroda*, **48** (2), 4–7 (*Feb.*, 1959). (*In Russian.*)

.4 *Sun*

(2176) **X-rays from the Sun's corona.** C. de Jager. *Hemel en Dampkring*, **56**, 135–9 (*July–Aug.*, 1958). (*In Dutch.*)

.5 *Planets (except Earth)*

(2177) **Our neighbours in space. Pt. III. Mars.** A. P. Borrell. *Astronautica*, **2**, 123–8 (*Dec.*, 1956). (*In Spanish.*)

(2178) **Saturn.** H. N. D. Wright. *Spaceflight*, **1**, 278–81 (*July*, 1958).

(2179) **Photometric study of the seasonal variation of the brilliance of the dark regions of the planet Mars.** J. H. Focas. *C.R. Acad. Sci., Paris*, **248**, 924–6 (16 *Feb.*, 1959). (*In French.*) (9 *refs.*)

.6 *Earth*

(2180) **Determination of the Earth's gravitational potential from observations on Sputnik 2 (1957 β).** A. H. Cook. *Geophys. J.*, **1**, 341–5 (*Dec.*, 1958).

(2181) **Preliminary information concerning geomagnetic measurement by the third Soviet artificial Earth satellite.** S. Sh. Dolginov, L. N. Zhuzgov and N. V. Pushkov. *Isskusstvenie Sputniki Zemli*, (2), 50–3 (25 *Dec.*, 1958). (*In Russian.*) (2 *refs.*)

(2182) **Earth and its environment.** S. Chapman. *Inst. Radio Engrs. Proc.*, **47**, 137–41 (*Feb.*, 1959).

(2183) **A new value for the Earth's flattening, derived from measurements of satellite orbits.** D. G. King-Hele and R. H. Merson. *Nature*, **183**, 881–2 (28 *March*, 1959). Letter. Combined data from *Sputnik* 2 and *Vanguard* 1 gives 1/(298·20 ± 0·03). (4 *refs.*)

.7 *Moon*

[*See also* abstracts nos. 2545, 2577.]

(2184 **An apparent volcanic eruption in the lunar crater Alphonsus.** W. H. Haas. *Strolling Astronomer*, **12**, 119–23 (*Oct.–Dec.*, 1958).

(2185) **Simulation of lunar craters: a blow-hole theory.** A. G. Gaydon and R. C. M. Learner. *Nature*, **183**, 37 (3 *Jan.*, 1959). Letter. Suggests formation by fountains of dust blown out by trapped gas. (2 *refs.*)

(2186) **Origin of the lunar craters and maria.** Z. Kopal. *Nature*, **183**, 169–70 (17 *Jan.*, 1959). Letter. Suggests formation by cometary impact. Cometry heads contain frozen hydrocarbons and unstable compounds such as hydrogen peroxide. This would act as a high explosive and the heat would produce a lava 'sea.' (6 *refs.*)

(2187) **Volcanoes on the Moon.** J. H. Fremlin. *Nature*, **183**, 239 (24 *Jan.*, 1959). Letter. Arguments in favour of trapped gases.

(2188) **Origin of the lunar craters and maria.** W. G. van Dorn; Z. Kopal. *Nature*, **183**, 737–8 (14 *March*, 1959). Two letters. van Dorn states that impact energy to produce given size of crater is higher than previously postulated. On basis of underground atomic explosions he doubts Kopal's comet theory of crater formation. Kopal queries effects of comets if they have not produced craters. (3 *refs.*)

(2189) **Sub-surface temperatures on the Moon.** J. C. Jaeger; J. H. Fremlin. *Nature*, **183**, 1316–8. (9 *May*, 1959). Two letters. Jaeger criticizes Fremlin's results, *Nature*, **183**, 239 (24 *Jan.*, 1959) (*See also* abs. no 2187 *above*), as being too high owing to the assumption of too high a heat flux and too low a thermal conductivity. (11 *refs.*)

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[*See also* abstract no. 2245]

(2190) **Acoustic method of measuring mechanical parameters of meteorites.** M. A. Isakovich and N. A. Roy. *Isskusstvenie Sputniki Zemli*, (2) 81–2 (25 *Dec.*, 1958). (*In Russian.*)

(2191) **Investigation of micrometeorites with rockets and satellites.** O. D. Komissarov, T. N. Nazarova, L. N. Neugodov, S. M. Polovskov and L. Z. Rusakova. *Isskusstvenie Sputniki Zemli*, (2), 54–8 (25 *Dec.*, 1958). (*In Russian.*) (11 *refs.*)

.9 *Comets*

[*See* abstracts nos. 2186, 2188]

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(2192) **The equations of motion in a multicomponent chemically reacting gas.** S. M. Scala. General Electric Co., Tech. Information Series, Rept. R58SD205, 38 pp. (*Dec.*, 1957.)

(2193) **Boundary conditions for the flow of a multicomponent gas.** D. E. Rossner. *Jet Propulsion*, **28**, 555–6 (*Aug.*, 1958). (5 *refs.*).

(2194) **Verification of general relativity by means of artificial planets.** J. J. Gilvarry, *Nature*, **183**, 666–7 (7 *March*, 1959). Letter. Shows that the controllable orbit of an artificial planet can be selected to yield a very large relativity advance of perihelion. (4 *refs.*)

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(2195) **Knowledge and possibilities in gravity research.** A. R. Weyl. *Weltraumfahrt*, **9**, 100–6 (*Dec.*, 1958) (*In German*).

.5 *Heat and Thermodynamics*

(2196) **The kinetics of heat transfer by convection and radiation with respect to specular surfaces.** E. Sänger. *Rev. Asoc. Argent. Interplanet.*, **4** (16/17), 31–41 (*July–Dec.*, 1957). (*In Spanish.*)

(2197) **Recent advances in convective heat transfer with dissociation and atom recombination.** D. E. Rossner. *Jet Propulsion*, **28**, 445–51 (*July*, 1958). (51 *refs.*)

.7 *Cosmic Radiation*

[*See also* abstract no. 2360]

(2198) **Measuring cosmic radiation with artificial Earth satellites.** S. N. Vernov, N. L. Grigorov, Yu. I. Logachev and A. E. Chudakov. *Isskusstvenie Sputniki Zemli* (1), 5–8 (24 *Nov.*, 1958). (*In Russian.*) (3 *refs.*)

(2199) **Heavy nuclei in primary cosmic radiation.** L. V. Kurnosova, L. A. Razorenov and M. I. Fradkin. *Isskusstvenie Sputniki Zemli*, (2), 70–4 (25 *Dec.*, 1958). (*In Russian.*)

(2200) **Study of the soft component of cosmic rays beyond the limits of the atmosphere.** S. N. Vernov, P. V. Vakulov, E. V. Gorchakov, Yu. I. Logachev and A. E. Chudakov. *Isskusstvenie Sputniki Zemli*, (2), 61–9 (25 *Dec.*, 1958). (*In Russian.*)

(2201) **Cosmic-ray instrumentation in the first U.S. Earth satellite.** G. H. Ludwig. *Rev. Sci. Instrum.*, **30**, 223–9 (*April*, 1959). System used in 1958α (*Explorer I*) and results. (9 *refs.*)

.8 *Other Upper Atmosphere Phenomena*

[*See also* abstract no. 2358]

(2202) **Observation of high intensity radiation by satellites 1958 alpha and gamma.** J. A. Van Allen, G. H. Ludwig, E. C. Ray and C. E. McIlwain. *Jet Propulsion*, **28**, 588–92 (*Sept.*, 1958).

(2203) **High-wind layer in the stratosphere.** H. Faust. *Raktech. u. Raumforsch.*, **2**, 117–20 (*Oct.–Dec.*, 1958). (*In German.*) (16 *refs.*)

(2204) **Determination of the density of the upper atmosphere by the secular variation of the orbital elements of the first two artificial Earth satellites.** P. E. El'yasberg. *Isskusstvenie Sputniki Zemli*, (1), 21–4 (24 *Nov.*, 1958). (*In Russian.*) (4 *refs.*)

(2205) **Rocket measurement of electron concentration in the ionosphere with the help of an ultra-short wave dispersion interferometer.** K. I. Gringauz. *Isskusstvenie Sputniki Zemli*, (1), 62–6 (24 *Nov.*, 1958). (*In Russian.*) (8 *refs.*)

(2206) **Determination of atmospheric density by observation of the initial retardation of artificial Earth satellites.** M. L. Lidov. *Isskusstvenie Sputniki Zemli*, (1), 9–20 (24 *Nov.*, 1958). (*In Russian.*) (8 *refs.*)

(2207) **A new instrument for measuring atmospheric density and temperature at satellite altitudes.** A. J. Dessler, W. B. Hanson, M. Hertzberg, D. D. McKibbin and R. C. Wrigley. *Jet Propulsion*, **28**, 837–8 (*Dec.*, 1958). (2 *refs.*)

(2208) **Investigation of the ionic composition of the atmosphere of the Earth by rockets and satellites.** V. G. Istomin. *Isskusstvenie Sputniki Zemli*, (2), 32–5 (25 *Dec.*, 1958). (*In Russian.*) (3 *refs.*)

(2209) **Soviet investigation of the ionosphere with the aid of rockets and artificial Earth satellites.** V. I. Krasovskii. *Isskusstvenie Sputniki Zemli*, (2), 36–49 (25 *Dec.*, 1958). (*In Russian.*) (16 *refs.*)

(2210) **Discovery of corpuscles with the help of the third artificial Earth satellite.** V. I. Krasovskii, Yu. M. Kushnir, G. A. Bordovskii, G. F. Zakhorov and E. M. Svetlitskii. *Isskusstvenie Sputniki Zemli*, (2), 59–60 (25 *Dec.*, 1958). (*In Russian.*) (1 *ref.*)

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(2212) **Agitation in gas caused by satellite flights.** B. A. Mirtov. *Isskusstvenie Sputniki Zemli*, (2), 17–25 (25 *Dec.*, 1958). (*In Russian.*) (7 *refs.*)

(2213) **Some results of measurements of the thermodynamic parameters of the stratosphere with the help of a meteorological rocket.** E. G. Shvidkovskii. *Isskusstvenie Sputniki Zemli*, (2), 10–16 (25 *Dec.*, 1958) (*In Russian.*) (1 ref.)

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(2216) **Rocket observations of the ionosphere.** H. Friedman. *Inst. Radio Engrs. Proc.*, **47**, 272–80 (*Feb.*, 1959).

(2217) **Exploration of the upper atmosphere with the help of the third Soviet Sputnik.** V. I. Krasovskii. *Proc. Inst. Radio Engrs.*, **47**, 289–96 (*Feb.*, 1959). Paper presented at Ninth Congress of the International Astronautical Federation, Aug., 1958.

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(2224) **Density of the atmosphere at heights between 200 km. and 400 km., from analysis of artificial satellite orbits.** D. G. King-Hele. *Nature*, **183**, 1224–7 (2 *May*, 1959). Reviews previously deduced figures and presents new figures based on consistent analysis of all ten satellites launched up to end of 1958. (26 *refs.*)

(2225) **Van Allen radiation of solar origin.** P. J. Kellogg. *Nature*, **183**, 1295–7 (9 *May*, 1959). Suggests origin in streams of solar gas which become trapped in Earth's magnetic field. (7 *refs.*)

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(2226) **New era dawns for flight materials and structures.** G. Gerard. *Astronautics*, **3** (8), 20–1, 46 (*Aug.*, 1958).

(2227) **Materials for rockets and missiles.** R. G. Frank and W. F. Zimmerman. $4.50 *Macmillan, N.Y.*, 31s. 6d., *Macmillan, London* (1959).

(2228) **We need better materials for rockets.** A. S. Neiman. *Steel*, **144**, 96–7 (2 *Feb.*, 1959).

(2229) **Materials for missiles and the space-age.** J. E. Allen. *Aeroplane*, **96**, 248–252 (27 *Feb.*, 1959). Lists the components of missiles which are limited in performance by the limitations of present-day materials, reviews the properties of metals and some other materials for these applications.

(2230) **State of the art: structures and materials.** *Space-Aeronautics*, **31** (3), 40–1 (*March*, 1959). A review of structural trends as work tends from aircraft to spacecraft, and the materials to be watched for re-entry heating application.

.2 *Chemistry*

(2231) **Toxicity and personal decontamination of boron hydride propellant fuels.** S. Rothberg, J. L. Colbourn and R. Salvatore. *Jet Propulsion*, **28**, 762–4 (*Nov.*, 1958). (9 *refs.*)

.3 *Metallurgy*

[*See also* abstracts nos. 2227–30, 2479, 2481, 2500, 2517]

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(2233) **Space age: what's in it for metalworking?** *Amer. Machinist*, **10**, 823–4 (6 *Oct.*, 1958).

(2234) **How metals help control a satellite's temperature.** P. M. Unterweiser. *Iron Age*, **182**, 105–7 (6 *Nov.*, 1958).

(2235) **Missile aluminum uses increase.** P. Means. *Missiles and Rockets*, **5** (28), 18–20 (6 *July*, 1959).

(2236) **Aluminum in missiles.** W. K. Kinner. *Light Metal Age*, **16**, 8–11 (*Dec.*, 1958).

(2237) **Motor development depends on alloys.** N. L. Baker *Missiles and Rockets*, **4** (22), 25, 27, 29 (1 *Dec.*, 1958).

(2238) **Coating for re-entry.** W. L. Aves. *Metal Progr.*, **75**, 90–4, 189C, 190 (*March*, 1959).

(2239) **Metals used in the Vanguard.** C. Hirst. *Metal Progr.*, **75**, 73–6 (*March*, 1959).

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(2242) **Design tips for cryogenic storage vessels.** G. F. Sulfrian. *Space-Aeronautics*, **31** (6), 79–80, 82, 84, 86 (*June*, 1959). The need for better specification of requirements and good quality control as well as good design in the production of vessels for storing very cold liquids.

(2243) **Steels for hypersonic missiles.** R. Oppenheim. *Luftfahrttechnik*, **5** (7), 237–43 (*July*, 1959). (*In German.*) The characteristics, advantages and drawbacks, and applications of various categories of steel to be considered for use in hypersonic airframes. Considers highly resistant low-alloy steels, hot-working steels, heat treatable 12% Cr steels, cold-rolled stainless Cr-Ni steels, age-hardenable stainless steels, age-hardenable austenitic steels, as well as highly heat-resistant alloys. (29 *refs.*)

.4 *Refractories*

(2244) **Means of protection for materials for reaction motors operating with unstable combustion.** B. Langenecker. *Fusées*, **3**, 77–85 (*July*, 1958). (*In French.*) (24 *refs.*)

(2245) **Meterorites, satellites and ceramics.** J. S. Rinehart. *Amer. Ceram. Soc. Bull.*, **37**, 461–7 (15 *Nov.*, *1958*).

.5 *Plastics*

(2246) **Reinforced plastics for rocket and missile applications at very high temperatures.** M. W. Riley. *Matls. Des. Engng.*, **47** (6), 100–104 (*June*, 1958). [Extensive abstract in *Engrs. Dig.*, **19**, 308–9 (*July*, 1958)].

(2247) **Plastics for liquid rocket engines.** E. J. Zeilberger. *Astronautics*, **3** (8), 26–7, 76–9 (*Aug.*, 1958).

(2248) **Foamed styrene cuts missile costs: replaces wood as fuel cell fillers.** J. A. Soutar. *Modern Plastics*, **36**, 167–8 (*Nov.*, 1958).

(2249) **Urethane foam protects missile instruments.** *Electrical Manufacturing*, **63**, 134+ (*Feb.*, 1959).

.6 *Miscellaneous*

(2250) **Impact sensitivity of organic materials on exposure to liquid oxygen.** D. E. Clippinger and G. J. Morris. *Aircraft Engng.*, **31**, 204–5 (*July*, 1959). Various materials used as lubricants or for sealing joints or electrical insulation were tested by impact under liquid oxygen. Unsuitability for use was determined by occurrence of detonations. Lists of materials of varying susceptibility are given.

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(2253) **Speculations on extraterrestrial life.** S. S. Kind. *Spaceflight*, **1**, 288–90 (*July*, 1958). (3 *refs.*)

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.3 *Zoology*

(2255) **Scientific investigations of the flight of animals in artificial Earth satellites.** V. N. Chernov and V. I. Yakovlev. *Isskusstvenie Sputniki Zemli*, (1), 80–90 (24 *Nov.*, 1958). (*In Russian.*)

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(2257) **Human parameters of space flight.** P. A. Campbell. *Proc. Seventh AGARD General Assembly, Paris*, 63–73 (1957).

(2258) **Geophysical and biological investigation at extreme altitudes. Pt. I.** F. I. Ordway. *Rev. Asoc. Argent. Interplanet.*, **4** (15), 1–21 (*April–June*, 1957) (*In Spanish.*) (102 *refs.*)

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(2260) **Multi-directional protection against accelerations in space vehicles**. H. J. von Beckh. *Rev. Asoc. Argent. Interplanet.*, **5** (18/19), 9–15 (*Jan.–June*, 1958). (*In Spanish.*) (34 *refs.*) [In English in *J.B.I.S.*, **16**, 525–33 (*Sept.–Oct.*, 1958).] *See also* next abstract.

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(2262) **Cosmic radiation and its possible biological effects**. T. F. Sandeman. *Spaceflight*, **1**, 291–6 (*July*, 1958).

(2263) **The human system in space**. C. W. Reiniger. *Missiles and Rockets*, **4** (10), 33–4 (8 *Sept*, 1958).

(2264) **Human factors in missile design**. *Electrical Manufacturing*, **62**, 9–10 (*Oct*,. 1958).

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(2274) **The direct measurement of local skin friction on Viking No. 13 during ascending flight**. F. W. Feuter and W.C . Lyons. *Univ. Texas, Defense Res. Lab., CM* 917 (*DRL*-414), 32 pp. (*Jan.*, 1958).

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(2277) **New technique helps solve re-entry problem**. *Industr. Labs.*, **9**, 67–8 (*Dec.*, 1958).

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(2278) **Dyna-Soar brings out new Martin team idea**. D. E. Perry. *Missiles and Rockets*, **4** (21), 16–18, 20 (24 *Nov.*, 1958).

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6—ASTRONAUTICS

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(2282) **Fundamental basis of space flight**. W. O Davis. *J. Astronautics*, **3**, 9–10, 25 (*Spring*, 1956).

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(2284) **Into other worlds**. R. L. Green. 190 pp., 16s., *Abelard-Schuman, London* (1957).

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(2286) **Vistas in astronautics: first annual Air Force Office of Scientific Research Astronautics Symposium (co-sponsored with Convair division, General Dynamics Corporation)**. Ed. M. Alperin, M. Stern and H. Wooster, 330 pp. $15.00 *Pergamon Press, N.Y.*, 105s. *Pergamon Press, London.* International series of monographs on aeronautical science and space flight. Division 7: Astronautics division, vol. 1. (1958.) Papers presented at symposium, held at San Diego, Feb., 1957, arranged under headings re-entry, tracking and communications, environment and measurements, propulsion, orbits, human factors. (*Refs.*) Reviewed, *J.B.I.S.*, 1959–60, **17**, 111.

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(2292) **On the optimization of multistage rockets**. H. H. Hall and E. D. Zambelli. *Jet Propulsion*, **28**, 463–5 (*July*, 1958). (4 *refs.*)

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(2294) **The optimization of the N-step rocket with different construction parameters and propellant specific impulses in each stage**. M. Subotowicz. *Jet Propulsion*, **28**, 460–3 (*July*, 1958).

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(2303) **Space vehicles, satellites, and missiles.** *Electr. Engng., N.Y.*, **77**, 1077–95 (*Dec.*, 1958). Symposium.

(2304) **Calculation of re-entry velocity profile.** A. A. Adler. *Jet Propulsion*, **28**, 827–8 (*Dec.*, 1958). (1 *ref.*)

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